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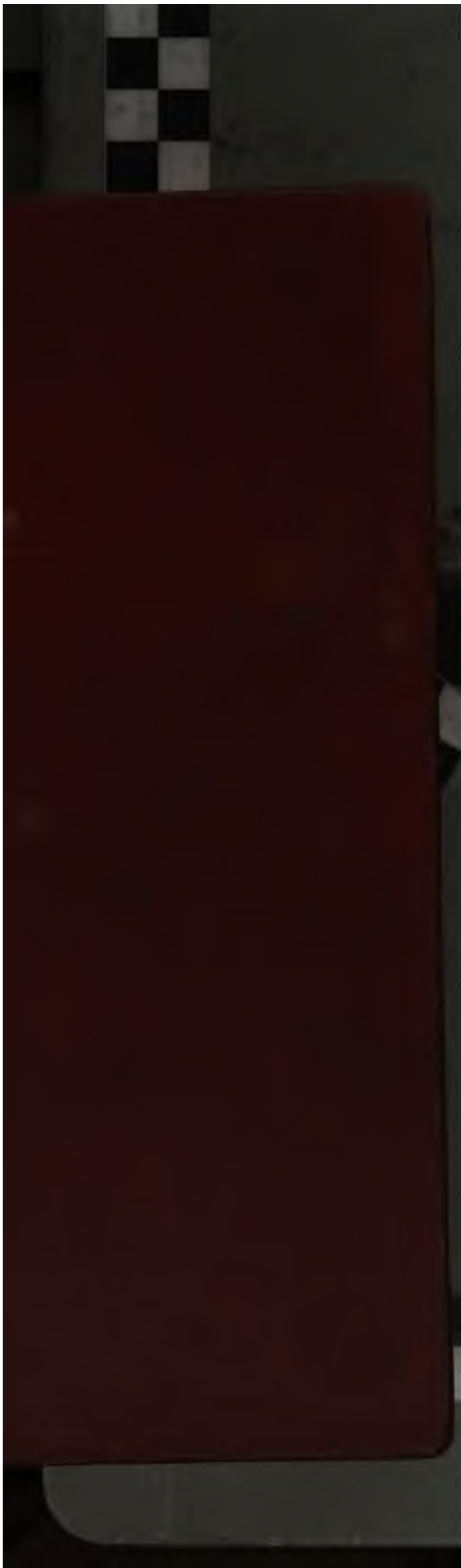
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Editor-in-Chief

FRANK W. GUNSAULUS

PRESIDENT ARMOUR INSTITUTE OF TECHNOLOGY

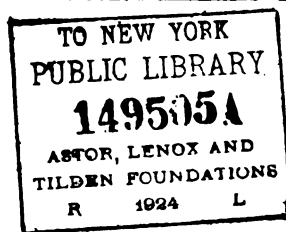
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Editor-in-Chief
FRANK W. GUNSAULUS
President Armour Institute of Technology.

Writers and Collaborators

F. B. CROCKER, E. M., Ph. D.
Head of Dept. of Electrical Engineering, Columbia University.
Past President American Institute of Electrical Engineers.

WILLIAM T. McCLEMENT, A. M.
Professor of Chemical Engineering, Armour Institute of Technology.

WILLIAM ESTY, S. B., M. A.
Head of Dept. of Electrical Engineering, Lehigh University.

VICTOR C. ALDERSON, D. Sc.
President, Colorado School of Mines.

DUGALD C. JACKSON, C. E.
Head of Dept. of Electrical Engineering, University of Wisconsin.

LOUIS DERR, S. B., A. M.
Associate Professor of Physics, Massachusetts Institute of Technology.

HOWARD M. RAYMOND, S. B.
Dean of Engineering Studies, Armour Institute of Technology.

Writers and Collaborators—Continued

KEMPSTER B. MILLER, M. E.

Telephone Expert and Consulting Engineer. Author of "American Telephone Practice."

~

WALTER S. LELAND, S. B.

Instructor in Naval Architecture, Massachusetts Institute of Technology.
American Society of Naval Architects and Marine Engineers.

~

GEORGE C. SHAAD, B. S., E. E.

Assistant Professor of Electrical Engineering, University of Wisconsin.

~

CHARLES DICKERMAN

Refrigerating Engineer, Pennsylvania Iron Works Co.

~

H. C. CUSHING, JR.

Consulting Electrical Engineer. Author of "Standard Wiring for Electric Light and Power."

~

ALBERT F. HALL, S. B.

American Society of Mechanical Engineers.
American Society of Naval Architects and Marine Engineers.
Institute of Mechanical Engineers of England.
German Society of Engineers in Germany.
Associate Member Institute of Civil Engineers of England.

~

ALFRED E. PHILLIPS, C. E., Ph. D.

Professor of Civil Engineering, Armour Institute of Technology.

~

CHARLES THOM

Chief Quadruplex Dept., Western Union Telegraph Co.

~

ARTHUR L. RICE, M. M. E.

Editor of "The Engineer," Chicago.

~

CHARLES E. DURYEA

First Vice-President, American Motor League.
Author of "Roadside Troubles."

Writers and Collaborators—Continued

FRANCIS H. BOYER

Constructing Engineer,
American Society of Mechanical Engineers.

LIONEL S. MARKS, S. B., M. M. E.

Assistant Professor of Mechanical Engineering, Harvard University,

CARL S. DOW, S. B.

American Society of Mechanical Engineers.

WALTER B. SNOW, S. B.

Mechanical Engineer, B. F. Sturtevant Co.
American Society of Mechanical Engineers.

SAMUEL G. McMEEN

Telephone Expert and Consulting Engineer.

GEORGE L. FOWLER, A. B., M. E.

Consulting Engineer.
American Society of Mechanical Engineers.
American Railway Master Mechanics Association.

LAWRENCE K. SAGER, S. B., M. P. L.

Patent Attorney and Electrical Expert,
Formerly Assistant Examiner U. S. Patent Office.

WILLIAM C. BOYRER, M. E., M. M. E.

Formerly Division Engineer, N. Y. and N. J. Telephone Co.

WILLIAM S. NEWELL, S. B.

With Bath Iron Works, Bath, Me.
Formerly Instructor Massachusetts Institute of Technology.

ROBERT V. PERRY, S. B., M. E.

Associate Professor of Machine Design, Armour Institute of Technology

Writers and Collaborators—Continued

NATHAN HASKELL DOLE

Editor, "American Dictionary and Cyclopedia," "The Library of the World's Best Literature," "The Literature of All Nations," "The International Library of Literature," etc.

~

ALFRED E. ZAPF, S. B.

Secretary, American School of Correspondence.
Editor, "The Technical World."

~

JOHN E. SNOW, M. S., E. E., A. M.

Associate Professor of Electrical Engineering, Armour Institute of Technology.
American Institute of Electrical Engineers.

~

MAURICE LEBOSQUET, S. B.

British Society of Chemical Industry.
American Chemical Society.

~

FREDERICK W. TURNER

Instructor in Machine Shop Work, Mechanics Arts High School, Boston.

~

JAMES RITCHEY

Instructor in Wood Working, Armour Institute of Technology.

~

JAMES R. CRAVATH

Western Editor, "Street Railway Journal," Chicago.

~

JOHN C. SHERMAN, S. B.

Formerly with the Westinghouse Companies.

~

MELVILLE B. WELLS, C. E.

Associate Professor of Bridge and Structural Engineering, Armour Institute of Technology.

~

CHARLES L. HUBBARD, S. B., M. E.

With S. Homer Woodbridge Company.
Heating, Ventilating and Sanitary Engineers.

Writers and Collaborators—Continued

R. F. SCHUCHARDT, B. S.

Testing Laboratory, Chicago Edison Company.

EDWARD R. MARKHAM

Instructor in Machine Shop Work, Rindge Manual Training School.
Formerly Superintendent Waltham Watch Tool Co.
American Society of Mechanical Engineers.

GEORGE F. GEBHARDT, M. E., M. A.

Professor of Mechanical Engineering, Armour Institute of Technology.

CHARLES E. LORD, S. B.

Manager of Patent Dept., Bullock Electric Mfg. Co

A. FREDERICK COLLINS

Author of "Wireless Telegraphy. Its History, Theory and Practice."

WILLIAM C. STIMPSON

Instructor in Foundry Work and Forging, Pratt Institute.

EVERETT E. KENT, S. B., LL. B.

Counselor at Law, Attorney and Expert in Patent Cases.

HENRI F. CHADWICK, S. B.

President Casino Technical Night School, Pittsburg

JOHN LORD BACON

Instructor in Forge Work, Lewis Institute.

ERVIN KENISON, S. B.

Instructor in Mechanical Drawing, Massachusetts Institute of Technology.

CHARLES L. GRIFFIN, S. B.

Mechanical Engineer, Semet-Solvay Co.
Formerly Professor of Machine Design, Pennsylvania State College.

Writers and Collaborators--Continued

PERCY H. THOMAS, S. B.

Chief Electrician, Cooper-Hewitt Electric Co.



RALPH H. SWEETSER, S. B.

Superintendent Algoma Steel Co., Ltd.

American Institute of Mining Engineers.

Formerly Instructor, Massachusetts Institute of Technology.



WILLIAM H. LAWRENCE, S. B.

Associate Professor of Architecture, Massachusetts Institute of Technology.



DAVID A. GREGG

Dept. of Architecture, Massachusetts Institute of Technology.



GILBERT TOWNSEND, S. B.

Architect with Post & McCord, New York City.



FRANK CHOUTEAU BROWN

Architect, Boston.



WALTER H. JAMES, S. B.

Dept. of Mechanical Drawing, Massachusetts Institute of Technology.



LAWRENCE S. SMITH, S. B.

Dept. of Mechanical Engineering, Massachusetts Institute of Technology.



NATHAN R. GEORGE, JR., A. M.

Dept. of Mathematics, Massachusetts Institute of Technology.



LOUIS A. OLNEY, A. C.

Head of Dept. of Textile Chemistry and Dyeing, Lowell Textile School.



HARRIS C. TROW, S. B., *Managing Editor*

Instructor in Electrical Engineering, American School of Correspondence.

American Institute of Electrical Engineers.

Authorities Consulted

THE editors have freely consulted the standard technical literature of Europe and America in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well known treatises should be in the library of every engineer.

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FRANCIS BACON CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University; Past President American Institute of Electrical Engineers.
Author of "Electric Lighting," "Practical Management of Dynamos and Motors."

SCHUYLER S. WHEELER, D. Sc.

Electrical Expert of the Board of Electrical Control, New York City; Member American Societies of Civil and Mechanical Engineers.
Author of "Practical Management of Dynamos and Motors."

WILLIAM M. BARR.

Member American Society of Mechanical Engineers,
Author of "Boilers and Furnaces," "Pumping Machinery," "Chimneys of Brick and Metal," etc.

SIMPSON BOLLAND.

Author of "The Iron Founder," "The Iron Founder's Supplement."

HORATIO A. FOSTER.

Member American Institute of Electrical Engineers; American Society of Mechanical Engineers; Consulting Engineer.
Author of "Electrical Engineer's Pocketbook."

J. FISHER-HINNEN.

Late Chief of the Drawing Department at the Oerlikon Works.
Author of "Continuous Current Dynamos"

WILLIAM F. DURAND, Ph. D.

Professor of Marine Engineering, Cornell University.
Author of "Resistance and Propulsion of Ships," "Practical Marine Engineering."

W. H. FORD, M. E.

Author of "Boiler Making for Boiler Makers."

Authorities Consulted—Continued

ROBERT GRIMSHAW, M. E.

Author of "Steam Engine Catechism," "Boiler Catechism," "Locomotive Catechism," "Engine Runners' Catechism," "Shop Kinks," etc.

GARDNER D. HISCOX, M. E.

Author of "Gas, Gasoline and Oil Engines."

GEORGE C. V. HOLMES.

Whitworth Scholar; Secretary of the Institute of Naval Architects, etc.
Author of the "Steam Engine."

WILLIAM HOUGHTALING.

Author of the "Steam Engine and Its Appliance."

WILLIAM KENT, M. E.

Consulting Engineer; Member of American Society of Mechanical Engineers, etc.
Author of "Strength of Materials," "Mechanical Engineer's Pocketbook," "Steam Boilers Economy," etc.

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, University of Wisconsin; Member of American Society of Mechanical Engineers; American Institute of Electrical Engineers.
Author of "A Textbook on Electro-Magnetism and the Construction of Dynamos," "Alternating Currents and Alternating Current Machinery."

JOHN PRICE JACKSON.

Professor of Electrical Engineering, Pennsylvania State College; Member of American Institute of Electrical Engineers.
Author of "Alternating Currents and Alternating Current Machinery."

GAETANO LANZA, S. B., C. E., M. E.

Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology; Member of American Society of Mechanical Engineers, etc.
Author of "Applied Mechanics."

C. W. MACCORD, A. M.

Professor of Mechanical Drawing, Stephens Institute of Technology.
Author of "Movement of Slide Valves by Eccentrics."

MANSFIELD MERRIMAN, Ph. D.

Professor of Civil Engineering, Lehigh University; Member of American Society Civil Engineers, etc.
Author of "Mechanics of Materials," "Treatise on Hydraulics," "Elements of Sanitary Engineering," etc.

CECIL H. PEABODY, S. B.

Professor of Marine Engineering and Naval Architecture, Massachusetts Institute of Technology.
Author of "Thermodynamics of the Steam Engine," "Tables of the Properties of Saturated Steam," "Valve Gears to Steam Engines," "Manual of Steam Engine Indicators," "Steam Boilers."

Authorities Consulted—Continued

EDWARD F. MILLER.

Professor of Steam Engineering, Massachusetts Institute of Technology.
Author of "Steam Boilers."

WILLIAM JOHN MACQUORN RANKINE, LL. D., F. R. S. S.

Civil Engineer; Late Regius Professor of Civil Engineering and Mechanics in University of Glasgow, etc.
Author of "Applied Mechanics," "The Steam Engine," "Civil Engineering," "Useful Rules and Tables," "Machinery and Mill Work," "A Mechanical Textbook."

KEMPSTER B. MILLER, M. E.

Consulting Engineer, and Telephone Expert.
Author of "American Telephone Practice."

MAURICE A. OUDIN, M. S.

Member of American Institute of Electrical Engineers.
Author of "Standard Polyphase Apparatus and Systems."

IRA REMSEN, M. D., Ph. D., LL. D.

President of Johns Hopkins University, and Professor of Chemistry, etc.
Author of the "Principles of Theoretical Chemistry," "Introduction to the Study of the Compounds of Carbon," "The Elements of Chemistry," "Inorganic Chemistry," etc.

WILLIAM RIPPER.

Professor of Mechanical Engineering in the Sheffield Technical School; Member of the Institute of Mechanical Engineers.
Author of "Machine Drawing and Design," "Practical Chemistry," "Steam," etc.

JOSHUA ROSE, M. E.

Author of "Mechanical Drawing Self Taught," "Modern Steam Engineering," "Steam Boilers," "The Slide Valve," "Pattern Makers Assistant," "Complete Machinist," etc.

LAMAR LYNDON, B. E., M. E.

Consulting Electrical Engineer; Associate Member of American Institute of Electrical Engineers; Member of American Electro-Chemical Society.
Author of "Storage Battery Engineering."

ROBERT H. THURSTON, C. E., Ph. B., A. M., LL. D.

Director of Sibley College, Cornell University.
Author of "Manual of The Steam Engine," "Manual of Steam Boilers," "History of the Steam Engine," etc.

SYLVANUS P. THOMPSON, D. Sc., B. A., F. R. S., F. R. A. S.

Principal and Professor of Physics in the City and Guilds of London Technical College.
Author of "Electricity and Magnetism," "Dynamo-Electric Machinery," "Polyphase Electric Currents," "Electromagnet," etc.

W. S. FRANKLIN and R. G. WILLIAMSON.

Joint Authors of "The Elements of Alternating Current."

Authorities Consulted—Continued

EDWARD R. MARKHAM.

Instructor in Machine Shop Work, Rindge Manual Training School; formerly Superintendent Waltham Watch Tool Co.
Author of "The American Steel Worker."

SAMUEL EDWARD WARREN.

Late Professor of Descriptive Geometry and Drawing, Massachusetts Institute of Technology.
Author of "General Problems in Shades and Shadows," "Shadows and Perspective," "Higher General Problems with Linear Perspective of Form," "Shadow and Reflection," etc.

THOMAS D. WEST.

Practical Moulder and Foundry Manager; Member American Society of Mechanical Engineers.
Author of "American Foundry Practice."

ROBERT WILSON.

Author of "Treatise on Steam Boilers," "Boiler and Factory Chimneys," etc.

WILLIAM C. UNWIN, F. R. S., M. Inst. C. E.

Professor of Civil and Mechanical Engineering, Central Technical College, City and Guilds of London Institute, etc.
Author of "Machine Design," "The Development and Transmission of Power from Central Stations," etc.

WILLIAM H. VAN DERVOORT, M. E.

Author of "Modern Machine Shop Tools."

J. A. EWING, M. A., B. Sc., F. R. S., M. Inst. C. E.

Professor of Mechanism and Applied Mechanics in the University of Cambridge.
Author of "The Steam Engine and Other Heat Engines."

ROLLA C. CARPENTER, M. S., C. E., M. M. E.

Professor of Experimental Engineering, Cornell University; Member of American Society Heating and Ventilating Engineers; Member American Society Mechanical Engineers.
Author of "Heating and Ventilating Buildings."

FRANK E. KIDDER, C. E.

Consulting Architect.
Author of "The Architect and Builder's Pocketbook."

A. E. SEATON.

Author of "A Manual of Marine Engineering."

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Author of "Modern Plumbing, Steam and Hot Water Heating."

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MECHANICAL DRAWING.

The subject of mechanical drawing is of great interest and importance to all mechanics and engineers. Drawing is the method used to show graphically the small details of machinery; it is the language by which the designer speaks to the workman; it is the most graphical way to place ideas and calculations on record. Working drawings take the place of lengthy explanations, either written or verbal. A brief inspection of an accurate, well-executed drawing gives a better idea of a machine than a large amount of verbal description. The better and more clearly a drawing is made, the more intelligently the workman can comprehend the ideas of the designer. A thorough training in this important subject is necessary to the success of everyone engaged in mechanical work. The success of a draftsman depends to some extent upon the quality of his instruments and materials. Beginners frequently purchase a cheap grade of instruments. After they have become expert and have learned to take care of their instruments they discard them for those of better construction and finish. This plan has its advantages, but to do the best work, strong, well-made and finely finished instruments are necessary.

INSTRUMENTS AND MATERIALS.

Drawing Paper. In selecting drawing paper, the first thing to be considered is the kind of paper most suitable for the proposed work. For shop drawings, a manilla paper is frequently used, on account of its toughness and strength, because the drawing is likely to be subjected to considerable hard usage. If a finished drawing is to be made, the best white drawing paper should be obtained, so that the drawing will not fade or become discolored with age. A good drawing paper should be strong, have uniform thickness and surface, should stretch evenly, and should neither repel nor absorb liquids. It should also allow considerable erasing without spoiling the surface, and it should lie smooth when stretched or when ink or colors are used. It is, of

course, impossible to find all of these qualities in any one paper, as for instance great strength cannot be combined with fine surface.

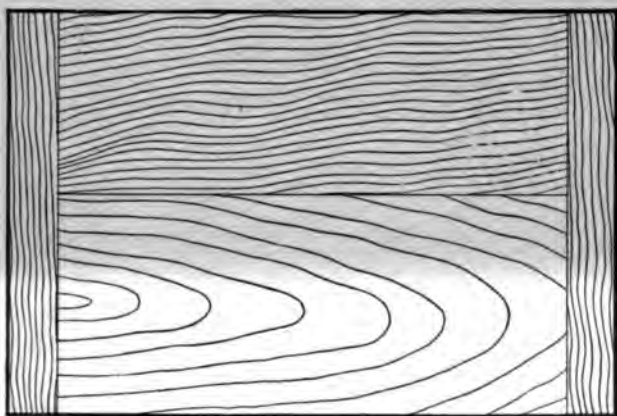
In selecting a drawing paper the kind should be chosen which combines the greatest number of these qualities for the given work. Of the better class Whatman's are considered by far the best. This paper is made in three grades; the *hot pressed* has a smooth surface and is especially adapted for pencil and very fine line drawing, the *cold pressed* is rougher than the hot pressed, has a finely grained surface and is more suitable for water color drawing; the *rough* is used for tinting. The cold pressed does not take ink as well as the hot pressed, but erasures do not show as much on it, and it is better for general work. There is but little difference in the two sides of Whatman's paper, and either can be used. This paper comes in sheets of standard sizes as follows:—

Cap,	13 × 17 inches.	Elephant,	23 × 28 inches.
Demy,	15 × 20 "	Columbia,	23 × 34 "
Medium,	17 × 22 "	Atlas,	26 × 34 "
Royal,	19 × 24 "	Double Elephant,	27 × 40 "
Super-Royal,	19 × 27 "	Antiquarian,	31 × 53 "
Imperial,	22 × 30 "	Emperor,	48 × 68 "

The usual method of fastening paper to a drawing board is by means of thumb tacks or small one-ounce copper or iron tacks. In fastening the paper by this method first fasten the upper left hand corner and then the lower right pulling the paper taut. The other two corners are then fastened, and sufficient number of tacks are placed along the edges to make the paper lie smoothly. For very fine work the paper is usually stretched and glued to the board. To do this the edges of the paper are first turned up all the way round, the margin being at least one inch. The whole surface of the paper included between these turned up edges is then moistened by means of a sponge or soft cloth and paste or glue is spread on the turned up edges. After removing all the surplus water on the paper, the edges are pressed down on the board, commencing at one corner. During this process of laying down the edges, the paper should be stretched slightly by pulling the edges towards the edges of the drawing board. The drawing board is then placed horizontally and left to dry. After the paper has become dry it will be found to be as smooth and tight as a

drum head. If, in stretching, the paper is stretched too much it is likely to split in drying. A slight stretch is sufficient.

Drawing Board. The size of the drawing board depends upon the size of paper. Many draftsmen, however, have several boards of various sizes, as they are very convenient. The drawing board is usually made of soft pine, which should be well seasoned and straight grained. The grain should run lengthwise of the board, and at the two ends there should be pieces about $1\frac{3}{4}$ or 2 inches wide fastened to the board by nails or screws. These end pieces should be perfectly straight for accuracy in using the T-square. Frequently the end pieces are fastened by a glued



DRAWING BOARD.

matched joint, nails and screws being also used. Two cleats on the bottom extending the whole width of the board, will reduce the tendency to warp, and make the board easier to move as they raise it from the table.

Thumb Tacks. Thumb tacks are used for fastening the paper to the drawing board. They are usually made of steel either pressed into shape, as in the cheaper grades, or made with a head of German silver with the point screwed and riveted to it. They are made in various sizes and are very convenient as they can be easily removed from the board. For most work however,

draftsmen use small one-ounce copper or iron tacks, as they can be forced flush with the drawing paper, thus offering no obstruction to the T-square. They also possess the advantage of cheapness.

Pencils. In pencilling a drawing the lines should be very fine and light. To obtain these light lines a hard lead pencil must be used. Lead pencils are graded according to their hardness, and are numbered by using the letter H. In general a lead pencil of 5H (or HHHHH) or 6H should be used. A softer pencil, 4H,

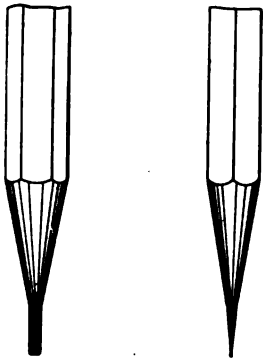


Fig. 1.

is better for making letters, figures and points. A hard lead pencil should be sharpened as shown in Fig. 1. The wood is cut away so that about $\frac{1}{4}$ or $\frac{3}{8}$ inch of lead projects. The lead can then be sharpened to a chisel edge by rubbing it against a bit of sand paper or a fine file. It should be ground to a chisel edge and the corners slightly rounded. In making the straight lines the chisel edge should be used by placing it against the T-square or triangle, and because of the chisel edge

the lead will remain sharp much longer than if sharpened to a point. This chisel edge enables the draftsman to draw a fine line exactly through a given point. If the drawing is not to be inked, but is made for tracing or for rough usage in the shop, a softer pencil, 3H or 4H, may be used, as the lines will then be somewhat thicker and heavier. The lead for compasses may also be sharpened to a point although some draftsmen prefer to use a chisel edge in the compasses as well as for the pencil.

In using a very hard lead pencil, the chisel edge will make a deep depression in the paper if much pressure is put on the pencil. As this depression cannot be erased it is much better to press lightly on the pencil.

Erasers. In making drawings, but little erasing should be necessary. However, in case this is necessary, a soft rubber should be used. In erasing a line or letter, great care must be exercised or the surrounding work will also become erased. To prevent this, some draftsmen cut a slit about 3 inches long and $\frac{1}{8}$ to $\frac{1}{4}$ inch wide in a card as shown in Fig. 2. The card is then

placed over the work and the line erased without erasing the rest of the drawing. An erasing shield of a form similar to that shown in Fig. 3 is very convenient, especially in erasing letters. It is made of thin sheet metal and is clean and durable.

For cleaning drawings, a sponge rubber may be used. Bread



Fig. 2.

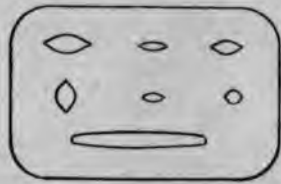


Fig. 3.

crumbs are also used for this purpose. To clean the drawing scatter *dry* bread crumbs over it and rub them on the surface with the hand.

T-Square. The T-square consists of a thin straight edge



Fig. 4.

called the blade, fastened to a head at right angles to it. It gets its name from the general shape. T-squares are made of various materials, wood being the most commonly used. Fig. 4 shows an ordinary form of T-square which is adapted to most work. In Fig. 5 is shown a T-square with edges made of ebony or mahogany, as these woods are much harder than pear wood or maple, which is generally used. The head is formed so as to fit against the left-hand edge of the drawing board, while the blade extends over the surface. It is desirable to have the blade of the T-square form a right angle with the head, so that the lines drawn with the T-square will be at right angles to the left-hand edge of the board. This, however, is not absolutely necessary, because the lines drawn with the T-square are always with reference to one edge of the

board only, and if this edge of the board is straight, the lines drawn with the T-square will be parallel to each other. The T-square should never be used except with the left-hand edge of the board, as it is almost impossible to find a drawing board with the edges parallel or at right angles to each other.

The T-square with an adjustable head is frequently very convenient, as it is sometimes necessary to draw lines parallel to each



Fig. 5.

other which are not at right angles to the left-hand edge of the board. This form of T-square is similar to the ordinary T-square already described, but the head is swiveled so that it may be clamped at any desired angle. The ordinary T-square as shown

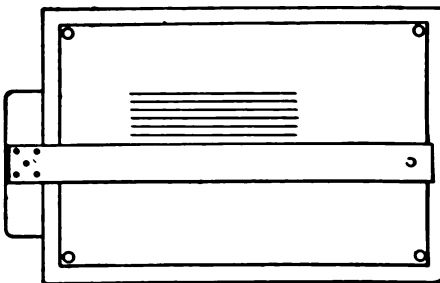


Fig. 6.

in Figs. 4 and 5 is, however, adapted to almost any class of drawing.

Fig. 6 shows the method of drawing parallel horizontal lines with the T-square. With the head of the T-square in contact with the left-hand edge of the board, the lines may be

drawn by moving the T-square to the desired position. In using the T-square the upper edge should always be used for drawing as the two edges may not be exactly parallel and straight, and also it is more convenient to use this edge with the triangles. If it is necessary to use a straight edge for trimming drawings or cutting the paper from the board, the lower edge of the T-square should be used so that the upper edge may not be marred.

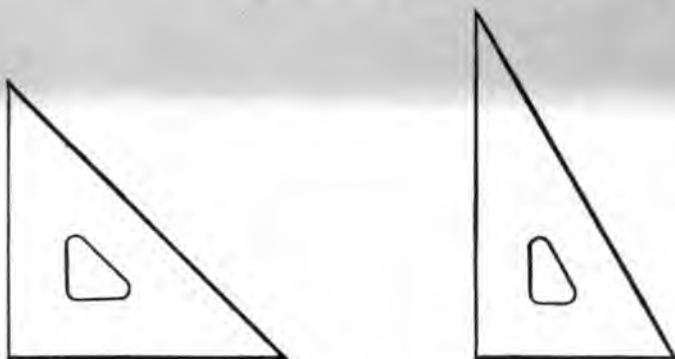
For accurate work it is absolutely necessary that the working edge of the T-square should be exactly straight. To test the

straightness of the edge of the T-square, two T-squares may be placed together as shown in Fig. 7. This figure shows plainly that the edge of one of the T-squares is crooked. This fact, however, does not prove that either one is straight, and for this determination a third blade must be used and tried with the two given T-squares successively.



Fig. 7.

Triangles. Triangles are made of various substances such as wood, rubber, celluloid and steel. Wooden triangles are cheap but are likely to warp and get out of shape. The rubber triangles are frequently used, and are in general satisfactory. The transparent celluloid triangle is, however, extensively used on account of its transparency, which enables the draftsmen to see the work already done even when covered with the triangle. In using a rubber or celluloid triangle take care that it lies perfectly flat or



TRIANGLES.

is hung up when not in use ; when allowed to lie on the drawing board with a pencil or an eraser under one corner it will become warped in a short time, especially if the room is hot or the sun happens to strike the triangle.

Triangles are made in various sizes, and many draftsmen have several constantly on hand. A triangle from 6 to 8 inches on a side will be found convenient for most work, although there are many cases where a small triangle measuring about 4 inches

on a side will be found useful. Two triangles are necessary for every draftsman, one having two angles of 45 degrees each and one a right angle; and the other having one angle of 60 degrees, one of 30 degrees and one of 90 degrees.

The value of the triangle depends upon the accuracy of the angles and the straightness of the edges. To test the accuracy of

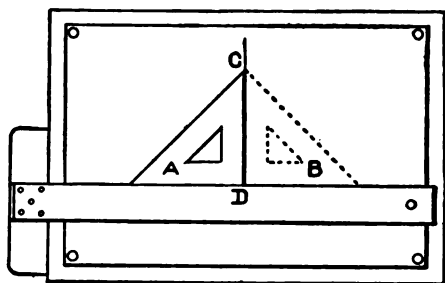


Fig. 8.

the right angle of a triangle, place the triangle with the lower edge resting on the edge of the T-square, as shown in Fig. 8. Now draw the line C D, which should be perpendicular to the edge of the T-square. The same triangle should then

be placed in the position shown at B. If the right angle of the triangle is exactly 90 degrees the left-hand edge of the triangle should exactly coincide with the line C D.

To test the accuracy of the 45-degree triangles, first test the right angle then place the triangle with the lower edge resting on the working edge of the T-square, and draw the line E F as shown in Fig. 9. Now without moving the T-square place the triangle so that the other 45-degree angle is in the position occupied by the first. If the two 45-degree angles coincide they are accurate.

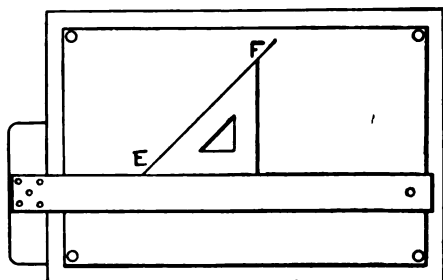


Fig. 9.

Triangles are very convenient in drawing lines at right angles to the T-square. The method of doing this is shown in Fig. 10. Triangles are also used in drawing lines at an angle with the horizontal, by placing them on the board as shown in Fig. 11. Suppose the line E F (Fig. 12) is drawn at any angle. and we wish to draw a line through the point P parallel to it.

First place one of the triangles as shown at A, having one edge coinciding with the given line. Now take the other triangle and place one of its edges in contact with the bottom edge of triangle A. Holding the triangle B firmly with the left hand the triangle A may be slipped along to the right or to the left until the edge of the triangle reaches the point P. The line M N may then be drawn along the edge of the triangle passing through the point P. In place of the triangle B any straight edge such as a T-square may be used.

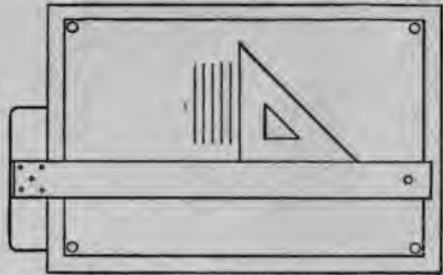


Fig. 10.

A line can be drawn perpendicular to another by means of the triangles as follows. Let E F (Fig. 13) be the given line, and suppose we wish to draw a line perpendicular to E F through the point D. Place the longest side of one of the triangles so that it coincides with the line E F, as the triangle is shown in position at A.

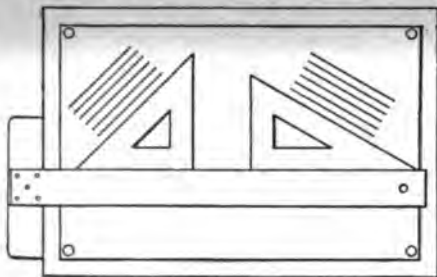


Fig. 11.

Place the other triangle (or any straight edge) in the position of the triangle as shown at B, one edge resting against the edge of the triangle A. Then holding B with the left hand, place the tri-

angle A in the position shown at C, so that the longest side passes through the point D. A line can then be drawn through the point D perpendicular to E F.

In previous figures we have seen how lines may be drawn making angles of 30, 45, 60 and 90 degrees with the horizontal. If it is desired to draw lines forming angles of 15 and 75 degrees the triangles may be placed as shown in Fig. 14.

In using the triangles and T-square almost any line may be drawn. Suppose we wish to draw a rectangle having one side

horizontal. First place the T-square as shown in Fig. 15. By moving the T-square up or down, the sides A B and D C may be drawn, because they are horizontal and parallel. Now place one of the triangles resting on the T-square as shown at E, and having the left-hand edge passing through the point D. The vertical

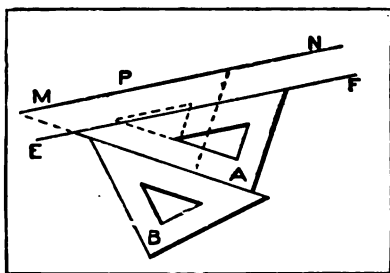


Fig. 12.

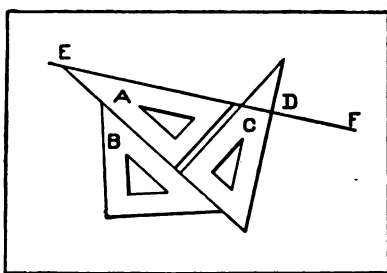


Fig. 13.

line D A may be drawn, and by sliding the triangle along the edge of the T-square to the position F the line B C may be drawn by using the same edge. These positions are shown dotted in Fig. 15.

If the rectangle is to be placed in some other position on the drawing board, as shown in Fig. 16, place the 45-degree triangle

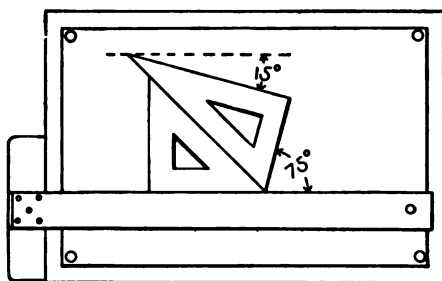


Fig. 14.

F so that one edge is parallel to or coincides with the side D C. Now holding the triangle F in position place the triangle H so that its upper edge coincides with the lower edge of the triangle F. By holding H in position and sliding the triangle F

along its upper edge, the sides A B and D C may be drawn. To draw the sides A D and B C the triangle should be used as shown at E.

Compasses. Compasses are used for drawing circles and arcs of circles. They are made of various materials and in various sizes. The cheaper class of instruments are made of brass, but they are unsatisfactory on account of the odor and the tendency to tarnish. The best material is German silver. It does not soil

readily, it has no odor, and is easy to keep clean. Aluminum instruments possess the advantage of lightness, but on account of the soft metal they do not wear well.

The compasses are made in the form shown in Figs. 17 and 18. Pencil and pen points are provided, as shown in Fig. 17. Either pen or pencil may be inserted in one leg by means of a shank and socket. The other leg is fitted with a needle point which is placed at the center of the circle. In most instruments the needle point is separate, and is made of a piece of round steel wire having a square shoulder at one or both ends. Below this shoulder the needle point projects. The needle is made in this form so that the hole in the paper may be very minute.

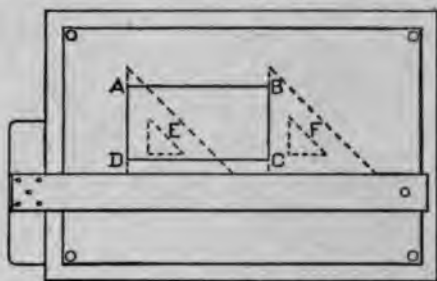


Fig. 15.

In some instruments lock nuts are used to hold the joint firmly in position. These lock nuts are thin discs of steel, with

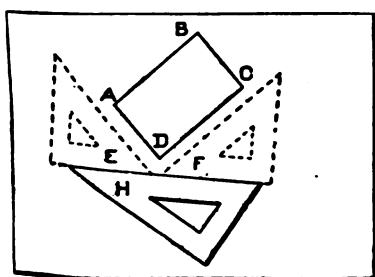


Fig. 16.

notches for using a wrench or forked key. Fig. 19 shows the detail of the joint of high grade instruments. Both legs are alike at the joint, and two pivoted screws are inserted in the yoke. This permits ample movement of the legs, and at the same time gives the proper stiffness. The flat surface of one of

the legs is faced with steel, the other being of German silver, in order that the rubbing parts may be of different metals. Small set screws are used to prevent the pivoted screws from turning in the yoke. The contact surfaces of this joint are made circular to exclude dust and dirt and to prevent rusting of the steel face.

Figs. 20, 21, and 22 show the detail of the socket; in some

instruments the shank and socket are pentagonal, as shown in Fig. 20. The shank enters the socket loosely, and is held in place by means of the screw. Unless used very carefully this arrangement is not durable because the sharp corners soon wear, and the pressure on the set screw is not sufficient to hold the shank firmly in place.

In Fig. 21 is shown another form of shank. This is round, having a flat top. A set screw is also used to hold this in position. A still better form of socket is shown in Fig. 22; the hole

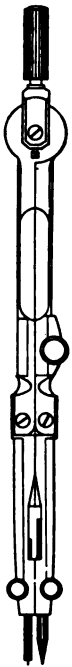


Fig. 17.

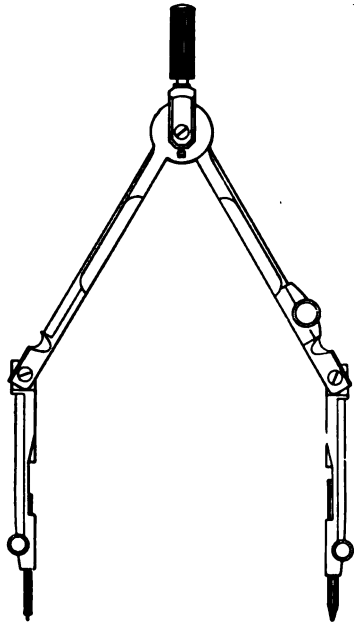
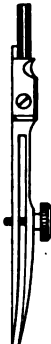
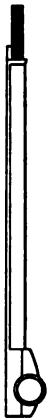


Fig. 18.

is made tapered and is circular. The shank fits accurately, and is held in perfect alignment by a small steel key. The clamping screw is placed upon the side, and keeps the two portions of the split socket together.

Figs. 17 and 18 show that both legs of the compasses are jointed in order that the lower part of the legs may be perpendicular to the paper while drawing circles. In this way the needle point makes but a small hole in the paper, and both nibs of

the pen will press equally on the paper. In pencilling circles it is not as necessary that the pencil should be kept vertical; it is a good plan, however, to learn to use them in this way both in pencilling and inking. The compasses should be held loosely between the thumb and forefinger. If the needle point is sharp, as it should be, only a slight pressure will be required to keep it in place. While drawing the circle, incline the compasses slightly in the direction of revolution and press lightly on the pencil or pen.

In removing the pencil or pen, it should be pulled out straight. If bent from side to side the socket will become enlarged and the shank worn; this will render the instrument inaccurate. For drawing large circles the lengthening bar shown in Fig. 17 should be used. When using the lengthening bar the

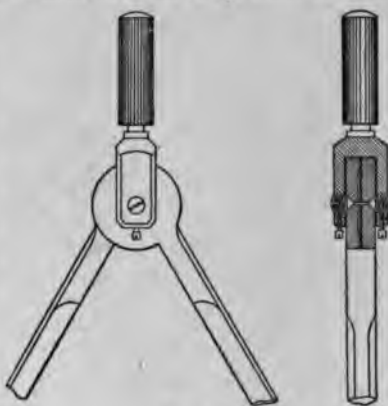


Fig. 19.

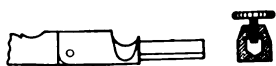


Fig. 20.

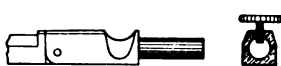


Fig. 21.

needle point should be steadied with one hand and the circle described with the other.

Dividers. Dividers, shown in Fig. 23, are made similar to the compasses. They are used for laying off distances on the drawing, either from scales or from other parts of the drawing. They



Fig. 22.



may also be used for dividing a line into equal parts. When dividing a line into equal parts the dividers should be turned in the opposite direction each time, so that the moving point passes alternately to the right and to the left. The instrument can then be operated readily with one hand. The points of the dividers should be very sharp so that the holes made in the paper will be small. If large holes are made in the paper, and the distances between

the points are not exact, accurate spacing cannot be done. Sometimes the compasses are furnished with steel divider points in addition to the pen and pencil points. The compasses may then be used either as dividers or as compasses. Many draftsmen use a *needle point* in place of dividers for making measurements from a scale. The eye end of a needle is first broken off and the needle then forced into a small handle made of a round piece of soft pine. This instrument is very convenient for indicating the intersection of lines and marking off distances.



Fig. 23.

Bow Pen and Bow Pencil. Ordinary large compasses are too heavy to use in making small circles, fillets, etc. The leverage of the long leg is so great that it is very difficult to draw small circles accurately. For this reason the bow compasses shown in Figs. 24 and 25 should be used on all arcs and circles having a radius of less than three-quarters inch. The bow compasses are also convenient for duplicating small circles such as those which represent boiler tubes, bolt holes, etc., since there is no tendency to slip.

The needle point must be adjusted to the same length as the pen or pencil point if very small circles are to be drawn. The adjustment for altering the radius of the circle can be made by turning the nut. If the change in radius is considerable the points should be pressed together to remove the pressure from the nut which can then be turned in either direction with but little wear on the threads.

Fig. 26 shows another bow instrument which is frequently used in small work in place of the dividers. It has the advantage of retaining the adjustment.

Drawing Pen. For drawing straight lines and curves that are not arcs of circles, the line pen (sometimes called the ruling pen) is used. It consists of two blades of steel fastened to a handle as shown in Fig. 27. The distance between the pen points can be adjusted by the thumb screw, thus regulating the width of the line to be drawn. The blades are given a slight curvature so that there is a cavity for ink when the points are close together.

The pen may be filled by means of a common steel pen or with the quill which is provided with some liquid inks. The pen should not be dipped in the ink because it will then be necessary to wipe the outside of the blades before use. The ink should fill the pen to a height of about $\frac{1}{4}$ or $\frac{3}{8}$ inch; if too much ink is placed in the pen it is likely to drop out and spoil the drawing. Upon finishing the work the pen should be carefully wiped with



Fig. 24.



Fig. 25.



Fig. 26.

chamois or a soft cloth, because most liquid inks corrode the steel.

In using the pen, care should be taken that both blades bear equally on the paper. If the points do not bear equally the line will be ragged. If both points touch, and the pen is in good condition the line will be smooth. The pen is usually inclined slightly in the direction in which the line is drawn. The pen



Fig. 27.

should *touch* the triangle or T-square which serve as guides, but it should not be pressed against them because the lines will then be uneven. The points of the pen should be close to the edge of the triangle or T-square, but should not touch it.

To Sharpen the Drawing Pen. After the pen has been used for some time the points become worn, and it is impossible

to make smooth lines. This is especially true if rough paper is used. The pen can be put in proper condition by sharpening it. To do this take a small, flat, close-grained oil-stone. The blades should first be screwed together, and the points of the pen can be given the proper shape by drawing the pen back and forth over the stone changing the inclination so that the shape of the ends will be parabolic. This process dulls the points but gives them the proper shape, and makes them of the same length.

To sharpen the pen, separate the points slightly and rub one of them on the oil-stone. While doing this keep the pen at an angle of from 10 to 15 degrees with the face of the stone, and give it a slight twisting movement. This part of the operation requires great care as the shape of the ends must not be altered. After the pen point has become fairly sharp the other point should be ground in the same manner. All the grinding should be done on the *outside* of the blades. The burr should be removed from the inside of the blades by using a piece of leather or a piece of pine wood.

Ink should now be placed between the blades and the pen tried. The pen should make a smooth line whether fine or heavy, but if it does not the grinding must be continued and the pen tried frequently.

Ink. India ink is always used for drawing as it makes a permanent black line. It may be purchased in solid stick form or as a liquid. The liquid form is very convenient as much time is saved, and all the lines will be of the same color; the acid in the ink, however, corrodes steel and makes it necessary to keep the pen perfectly clean.

Some draftsmen prefer to use the India ink which comes in stick form. To prepare it for use, a little water should be placed in a saucer and one end of the stick placed in it. The ink is ground by giving it a twisting movement. When the water has become black and slightly thickened, it should be tried. A heavy line should be made on a sheet of paper and allowed to dry. If the line has a grayish appearance, more grinding is necessary. After the ink is thick enough to make a good black line, the grinding should cease, because very thick ink will not flow freely from the pen. If, however, the ink has become too



MEDIUM PRICED DRAWING OUTFIT SHOWING THE INSTRUMENTS NECESSARY FOR PURSUING A COURSE IN MECHANICAL DRAWING.

thick, it may be diluted with water. After using, the stick should be wiped dry to prevent crumbling. It is well to grind the ink in small quantities as it does not dissolve readily if it has once become dry. If the ink is kept covered it will keep for two or three days.

Scales. Scales are used for obtaining the various measurements on drawings. They are made in several forms, the most convenient being the flat with beveled edges and the triangular. The scale is usually a little over 12 inches long and is graduated for a distance of 12 inches. The triangular scale shown in Fig. 28 has six surfaces for graduations, thus allowing many graduations on the same scale.

The graduations on the scales are arranged so that the drawings may be made in any proportion to the actual size. For mechanical work, the common divisions are multiples of two.



Fig. 28.

Thus we make drawings full size, half size, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, etc. If a drawing is $\frac{1}{4}$ size, 3 inches equals 1 foot, hence 3 inches is divided into 12 equal parts and each division represents one inch. If the smallest division on a scale represents $\frac{1}{16}$ inch, the scale is said to read to $\frac{1}{16}$ inch.

Scales are often divided into $\frac{1}{10}$, $\frac{2}{10}$, $\frac{3}{10}$, $\frac{4}{10}$, etc., for architects, civil engineers, and for measuring on indicator cards.

The scale should never be used for drawing lines in place of triangles or T-square.

Protractor. The protractor is an instrument used for laying off and measuring angles. It is made of steel, brass, horn and paper. If made of metal the central portion is cut out as shown in Fig. 29, so that the draftsman can see the drawing. The outer edge is divided into degrees and tenths of degrees. Sometimes the graduations are very fine. In using a protractor a very sharp hard pencil should be used so that the lines will be fine and accurate.

The protractor should be placed so that the given line (pro-

duced if necessary) coincides with the two O marks. The center of the circle being placed at the point through which the desired line is to be drawn. The division can then be marked with the pencil point or needle point.

Irregular Curve. One of the conveniences of a draftsman's

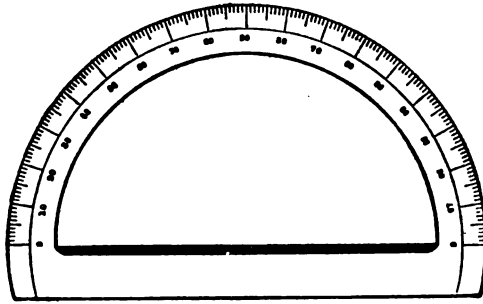


Fig. 29.

outfit is the French or irregular curve. It is made of wood, hard rubber or celluloid, the last named material being the best. It is made in various shapes, two of the most common being

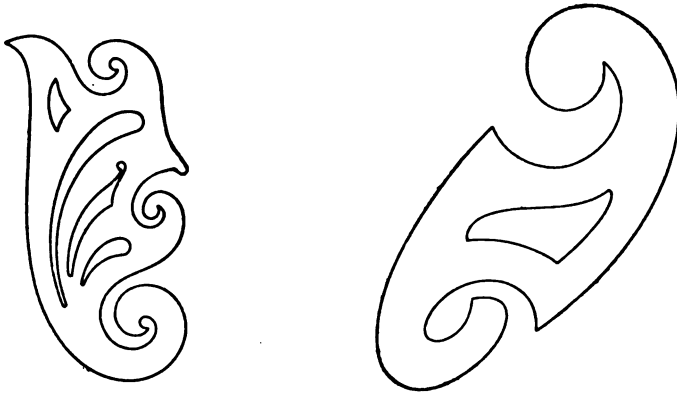


Fig. 30.

shown in Fig. 30. This instrument is used for drawing curves other than arcs of circles, and both pencil and line pen can be used.

To draw the curve, a series of points is first located and then the curve drawn passing through them by using the part of the irregular curve that passes through several of them. The

curve is shifted for this work from one position to another. It frequently facilitates the work and improves its appearance to draw a free hand pencil curve through the points and then use the irregular curve, taking care that it always fits at least *three* points.

In inking the curve, the blades of the pen must be kept

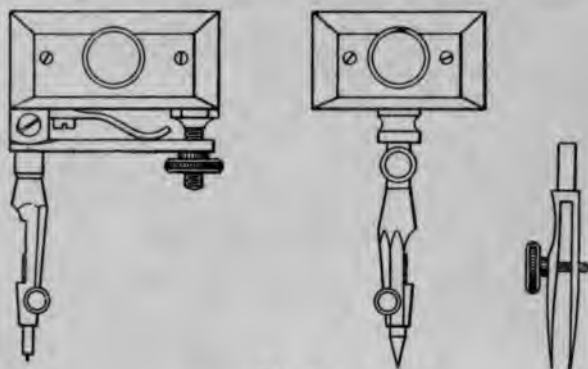


Fig. 31.

tangent to the curve, thus necessitating a continual change of direction.

Beam Compasses. The ordinary compasses are not large enough to draw circles having a diameter greater than about 8 or 10 inches. A convenient instrument for larger circles is found in the beam compasses shown in Fig. 31. The two parts called channels carrying the pen or pencil and the needle point are clamped to a wooden beam; the distance between them being equal to the radius of the circle. Accurate adjustment is obtained by means of a thumb nut underneath one of the channel pieces.

LETTERING.

No mechanical drawing is finished unless all headings, titles and dimensions are lettered in plain, neat type. Many drawings are accurate, well-planned and finely executed but do not present a good appearance because the draftsman did not think it worth while to letter well. Lettering requires time and patience; and if one wishes to letter rapidly and well he must practice.

Usually a beginner cannot letter well, and in order to produce a satisfactory result, considerable practice is necessary. Many

think it a good plan to practice lettering before commencing a drawing. A good writer does not always letter well; a poor writer need not be discouraged and think he can never learn to make a neatly lettered drawing.

In making large letters for titles and headings it is often necessary to use drawing instruments and mechanical aids. The small letters, such as those used for dimensions, names of materials, dates, etc., **should be made free hand.**

There are many styles of letters used by draftsmen. For titles, large Roman capitals are frequently used, although Gothic and block letters also look well and are much easier to make.



Fig. 32.

Almost any neat letter free from ornamentation is acceptable in the regular practice of drafting. Fig. 32 shows the alphabet of vertical Gothic capitals. These letters are neat, plain and easily made. The inclined or italicized Gothic type is shown in Fig. 33. This style is also easy to construct, and possesses the advantage that a slight difference in inclination is not apparent. If the vertical lines of the vertical letters incline slightly the inaccuracy is very noticeable.

The curves of the inclined Gothic letters such as those in the *B*, *C*, *G*, *J*, etc., are somewhat difficult to make free hand, especially if the letters are about one-half inch high. In the alphabet shown in Fig. 34, the letters are made almost wholly of

straight lines, the corners only being curved. These letters are very easy to make and are clear cut.

The first few plates of this work will require no titles; the only lettering being the student's name, together with the date and plate number. Later, the student will take up the subject of

A B C D E F G H I J
K L M N O P Q R
S T U V W X Y Z

Fig. 33.

lettering again in order to letter titles and headings for drawings showing the details of machines. For the present, however, inclined Gothic capitals will be used.

To make the inclined Gothic letters, first draw two parallel lines having the distance between them equal to the desired height of the letters. If two sizes of letters are to be used, the smaller should be about two-thirds as high as the larger. For the letters

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0

Fig. 34.

to be used on the first plates, draw two parallel lines $\frac{5}{32}$ inch apart. This is the height for the letters of the date, name, also the plate number, and should be used on all plates throughout this work, unless other directions are given.

In constructing the letters, they should extend fully to these lines, both at the top and bottom. They should not fall short of

the guide lines nor extend beyond them. As these letters are inclined they will look better if the inclination is the same for all. As an aid to the beginner, he can draw light pencil lines, about $\frac{1}{4}$ inch apart, forming the proper angle with the parallel lines already drawn. The inclination is often made about 70 degrees; but as a 60-degree triangle is at hand, it may be used. To draw these lines place the 60-degree triangle on the T-square as shown in Fig. 36. In making these letters the 60-degree lines will be found a great aid as a large proportion of the back or side lines have this inclination.

Capital letters such as *E, F, P, T, Z*, etc., should have the top lines coincide with the upper horizontal guide line. The bottom lines of such letters as *D, E, L, Z*, etc., should coincide with the lower horizontal guide line. If these lines do not coincide with the guide lines the words will look uneven. Letters, of which *C, G, O*, and *Q*, are types, can be formed of curved lines or of straight lines. If made of curved lines, they should have a little greater height than the guide lines to prevent their appearing smaller than the other letters. In this work they can be made of straight lines with rounded corners as they are easily constructed and the student can make all letters of the same height.

To construct the letter *A*, draw a line at an angle of 60 degrees to the horizontal and use it as a center line. Then from the intersection of this line and the upper horizontal line drop a vertical line to the lower guide line. Draw another line from the vertex meeting the lower guide line at the same distance from the center line. The cross line of the *A* should be a little below the center. The *V* is an inverted *A* without the cross line. For the letter *M*, the side lines should be parallel and about the same distance apart as are the horizontal lines. The side lines of the *W* are *not* parallel but are farther apart at the top. The *J* is not quite as wide as such letters as *H, E, N, R*, etc. To make a *Y*, draw the center line 60 degrees to the horizontal; the diverging lines are similar to those of the *V* but are shorter and form a larger angle. The diverging lines should meet the center line a little below the middle.

The lower-case letters are shown in Fig. 35. In such letters

as *m*, *n*, *r*, etc., make the corners sharp and not rounding. The letters *a*, *b*, *c*, *e*, *g*, *o*, *p*, *q*, should be full and rounding. The figures (see Fig. 32) are made as in writing — except the *4*, *6*, *8* and *9*.

The Roman numerals are made of straight lines as they are largely made up of *I*, *V* and *X*.

At first the copy should be followed closely and the letters drawn in pencil. For a time, the inclined guide lines may be used.

a b c d e f g h i j k l m n
o p q r s t u v w x y z

Fig. 35.

but after the proper inclination becomes firmly fixed in mind they should be abandoned. The horizontal lines are used at all times by most draftsmen. After the student has had considerable practice, he can construct the letters in ink without first using the pencil. Later in the work, when the student has become proficient in the simple inclined Gothic capitals, the vertical, block and Roman alphabets should be studied.

PLATES.

To lay out a sheet of paper for the plates of this work, the sheet, A B G F, (Fig. 36) is placed on the drawing board 2 or 3 inches from the left-hand edge which is called the *working edge*. If placed near the left-hand edge, the T-square and triangles can be used with greater firmness and the horizontal lines drawn with the T-square will be more accurate. In placing the paper on the board, always true it up according to the long edge of the sheet. First fasten the paper to the board with thumb tacks, using at least 4 — one at each corner. If the paper has a tendency to curl it is better to use 6 or 8 tacks, placing them as shown in Fig. 36. Thumb tacks are commonly used; but many draftsmen prefer one-ounce tacks as they offer less obstruction to the T-square and triangles.

After the paper is fastened in position, find the center of the

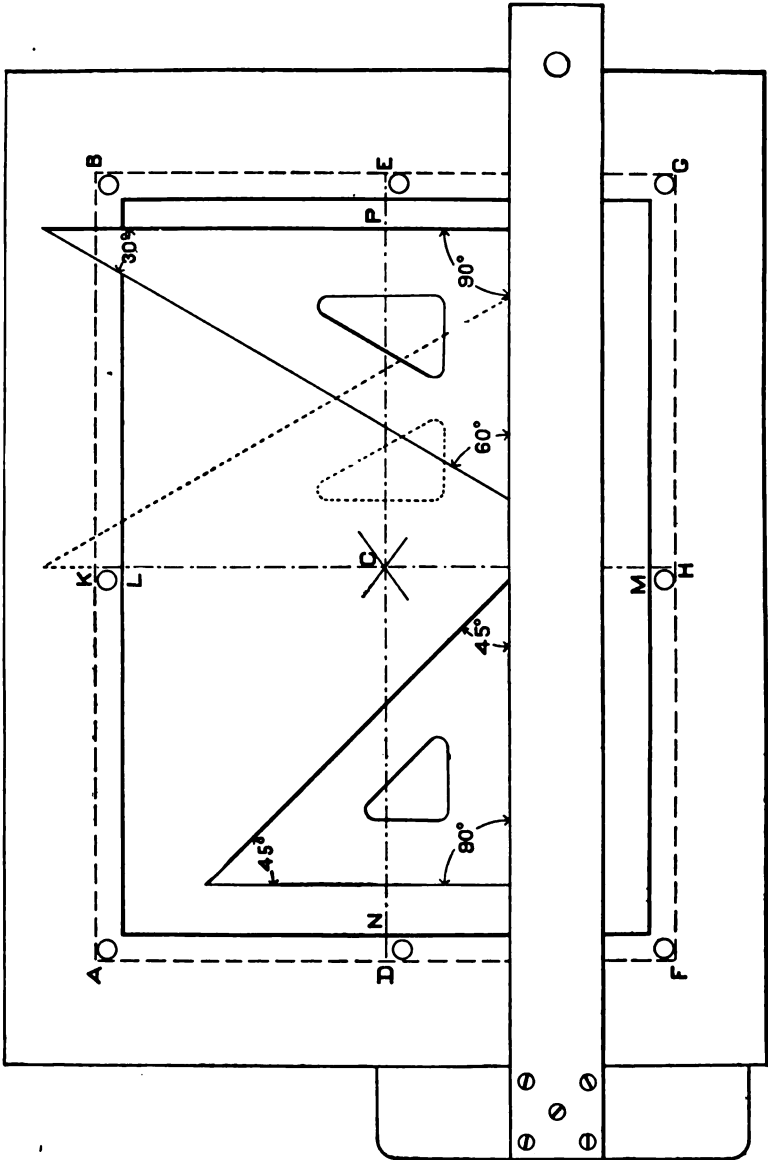


Fig. 36.

sheet by placing the T-square so that its upper edge coincides with the diagonal corners A and G and then with the corners F and B, drawing short pencil lines intersecting at C. Now place the T-square so that its upper edge coincides with the point C and draw the dot and dash line D E. With the T-square and one of the triangles (shown dotted) in the position shown in Fig. 36, draw the dot and dash line H C K. In case the drawing board is large enough, the line C H can be drawn by moving the T-square until it is entirely off the drawing. If the board is small, produce (extend) the line K C to H by means of the T-square or edge of a triangle. In this work always move the pencil from the left to the right or from the bottom upward; never (except for some particular purpose) in the opposite direction.

After the center lines are drawn measure off 5 inches above and below the point C on the line H C K. These points L and M may be indicated by a light pencil mark or by a *slight* puncture of one of the points of the dividers. Now place the T-square against the left-hand edge of the board and draw horizontal pencil lines through L and M.

Measure off 7 inches to the left and right of C on the center line D C E and draw pencil lines through these points (N and P) perpendicular to D E. We now have a rectangle 10 inches by 14 inches, in which all the exercises and figures are to be drawn. The lettering of the student's name and address, date, and plate number are to be placed *outside* of this rectangle in the $\frac{1}{2}$ -inch margin. In all cases lay out the plates in this manner and keep the center lines D E and K H as a basis for the various figures. The border line is to be inked with a heavy line when the drawing is inked.

Pencilling. In laying out plates, all work is first done in pencil and afterward inked or traced on tracing cloth. The first few plates of this course are to be done in pencil and then inked; later the subject of tracing and the process of making blue prints will be taken up. Every beginner should practice with his instruments until he can use them with accuracy and skill, and until he understands thoroughly what instrument should be used for making a given line. To aid the beginner in this work, the first three plates of this course are designed to give the student practice; they do

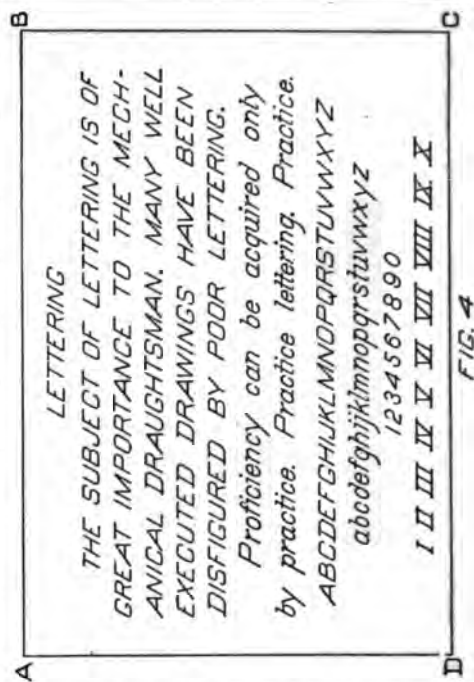
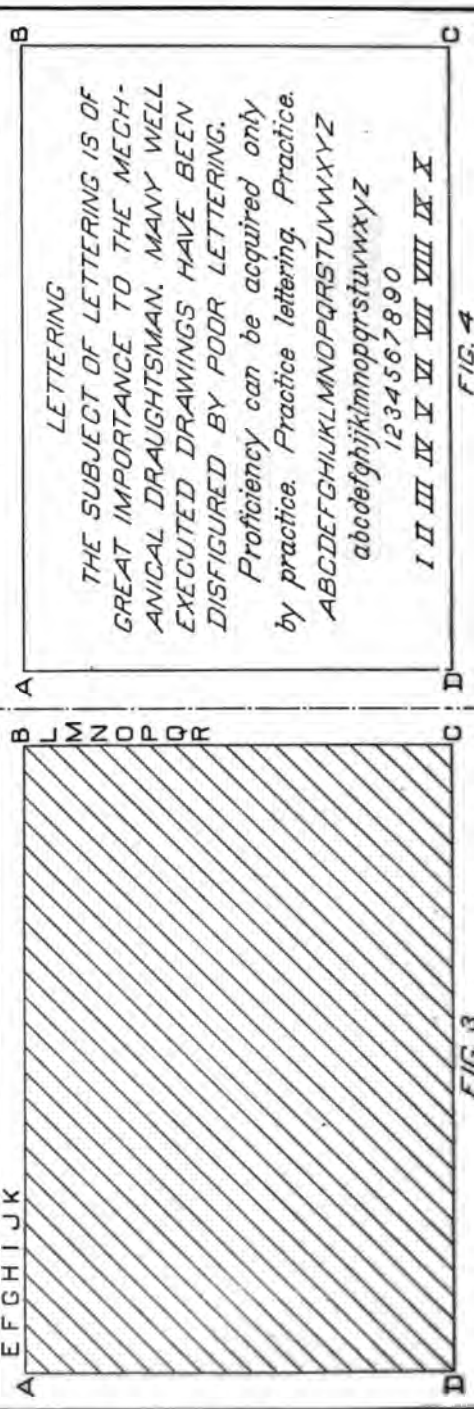
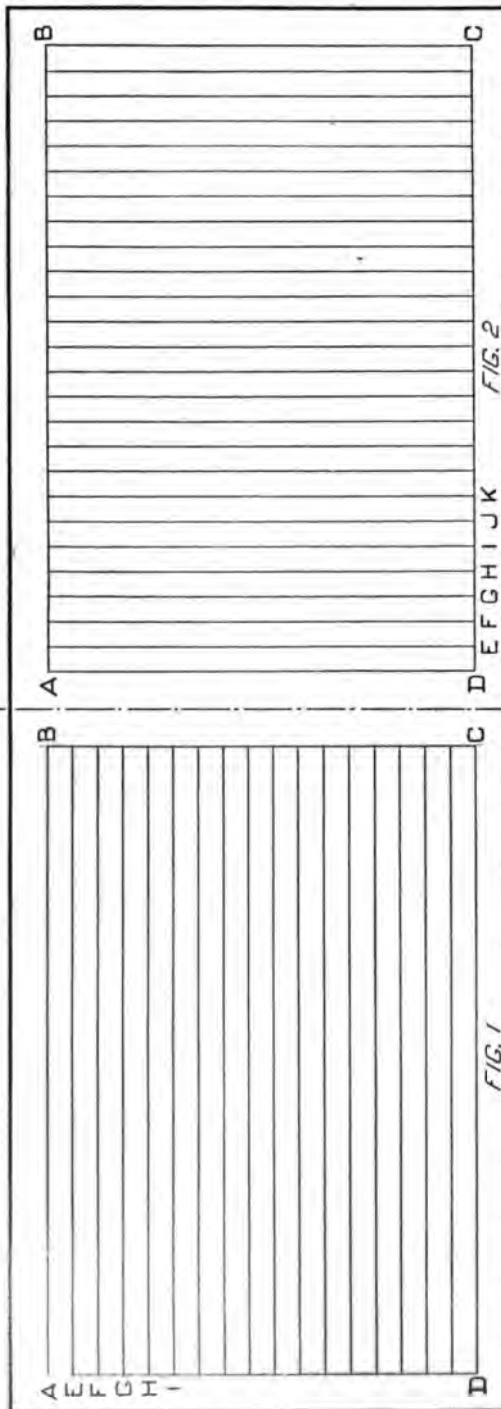
not involve any problems and none of the work is difficult. The student is strongly advised to draw these plates two or three times before making the one to be sent to us for correction. Diligent practice is necessary at first; especially on *PLATE I* as it involves an exercise in lettering.

PLATE I.

Pencilling. To draw *PLATE I*, take a sheet of drawing paper at least 11 inches by 15 inches and fasten it to the drawing board as already explained. Find the center of the sheet and draw fine pencil lines to represent the lines D E and H K of Fig. 36. Also draw the border lines L, M, N and P.

Now measure $\frac{3}{8}$ inch above and below the horizontal center line and, with the T-square, draw lines through these points. These lines will form the lower lines D C of *Figs. 1* and *2* and the top lines A B of *Figs. 3* and *4*. Measure $\frac{3}{8}$ inch to the right and left of the vertical center line; and through these points, draw lines parallel to the center line. These lines should be drawn by placing the triangle on the T-square as shown in Fig. 36. The lines thus drawn, form the sides B C of *Figs. 1* and *3* and the sides A D of *Figs. 2* and *4*. Next draw the line A B A B with the T-square, $4\frac{5}{8}$ inches above the horizontal center line. This line forms the top lines of *Figs. 1* and *2*. Now draw the line D C D C $4\frac{5}{8}$ inches below the horizontal center line. The rectangles of the four figures are completed by drawing vertical lines $6\frac{5}{8}$ inches from the vertical center line. We now have four rectangles each $6\frac{1}{4}$ inches long and $4\frac{1}{4}$ inches wide.

Fig. 1 is an exercise with the line pen and T-square. Divide the line A D into divisions each $\frac{1}{4}$ inch long, making a fine pencil point or *slight* puncture at each division such as E, F, G, H, I, etc. Now place the T-square with the head at the left-hand edge of the drawing board and through these points draw light pencil lines extending to the line B C. In drawing these lines be careful to have the pencil point pass *exactly* through the division marks so that the lines will be the same distance apart. Start each line in the line A D and do not fall short of the line B C or run over it. Accuracy and neatness in pencilling insure an accurate drawing. Some beginners think that they can correct inaccuracies while



LETTERING

THE SUBJECT OF LETTERING IS OF
GREAT IMPORTANCE TO THE MECH-
ANICAL DRAUGHTSMAN. MANY WELL
EXECUTED DRAWINGS HAVE BEEN
DISFIGURED BY POOR LETTERING.

Proficiency can be acquired only
by practice. Practice lettering. Practice.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz

1234567890

I II III IV V VI VII VIII IX X

FIG. 4

inking; but experience soon teaches them that they cannot do so.

Fig. 2 is an exercise with the line pen, T-square and triangle. First divide the lower line D C of the rectangle into divisions each $\frac{1}{4}$ inch long and mark the points E, F, G, H, I, J, K, etc., as in *Fig. 1*. Place the T-square with the head at the left-hand edge of the drawing board and the upper edge in about the position shown in *Fig. 36*. Place either triangle with one edge on the upper edge of the T-square and the 90-degree angle at the left. Now draw fine pencil lines from the line D C to the line A B passing through the points E, F, G, H, I, J, K, etc. To do this keep the T-square

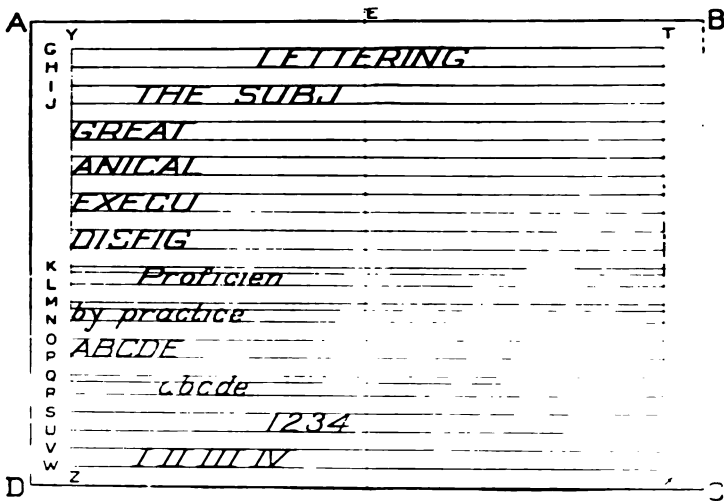


Fig. 37.

rigid and slide the triangle toward the right, being careful to have the edge coincide with the division marks in succession.

Fig. 3 is an exercise with the line pen, T-square and 45-degree triangle. First lay off the distances A E, E F, F G, G H, H I, I J, J K, etc., each $\frac{1}{4}$ inch long. Then lay off the distances B L, L M, M N, N O, O P, P Q, Q R, etc., also $\frac{1}{4}$ inch long. Place the T-square so that the upper edge will be below the line D C of *Fig. 2*. With the 45-degree triangle draw lines from A D and D C to the points E, F, G, H, I, J, K, etc., as far as the point B. Now draw lines from D C to the points L, M, N, O, P, Q, R, etc., as

far as the point C. In drawing these lines move the pencil away from the body, that is, from A D to A B and from D C to B C.

Fig. 4 is an exercise in free-hand lettering. The finished exercise, with all guide lines erased, should have the appearance shown in *Fig. 4* of *PLATE I*. The guide lines are drawn as shown in *Fig. 37*. First draw the center line E F and light pencil lines Y Z and T X, $\frac{3}{8}$ inch from the border lines. Now, with the T-square, draw the line G, $\frac{1}{4}$ inch from the top line and the line H, $\frac{5}{32}$ inch below G. The word "*LETTERING*" is to be placed between these two lines. Draw the line I, $\frac{3}{16}$ inch below H. The lines I, J, etc., to K are all $\frac{5}{32}$ inch apart.

We now practice the lower-case letters. Draw the line L, $\frac{3}{16}$ inch below K and a light line $\frac{1}{8}$ inch above L to limit the height of the small letters. The space between L and M is $\frac{5}{32}$ inch. The lines M and N are drawn in the same manner as K and L. The space between N and O should be $\frac{1}{4}$ inch. The line P is drawn $\frac{5}{32}$ inch below O. Q is also $\frac{5}{32}$ inch below P. The lines Q and R are drawn $\frac{3}{16}$ inch apart as are M and N. The remainder of the lines S, U, V and W are drawn $\frac{5}{32}$ inch apart.

The center line is a great aid in centering the word "*LETTERING*," the alphabets, numerals, etc. The words "*THE*" and "*Proficiency*" should be indented about $\frac{3}{4}$ inch as they are the first words of paragraphs. To draw the guide lines, mark off distances of $\frac{1}{4}$ inch on any line such as J and with the 60-degree triangle draw light pencil lines cutting the parallel lines. The letters should be sketched in pencil, the ordinary letters such as E, F, H, N, R, etc. being made of a width equal to about $\frac{3}{4}$ the height. Letters like A, M and W are wider. The space between the letters depends upon the draftsman's taste but the beginner should remember that letters next to an A or an L should be placed near them and that greater space should be left on each side of an I or between letters whose sides are parallel; for instance there should be more space between an N and E than between an E and H. On account of the space above the lower line of the L, a letter following an L should be close to it. If a T follows a T or the letter L follows an L they should be placed near together. In all lettering the letters should be placed so that the general effect is pleasing. After the four figures are

completed, the lettering for name, address and date should be pencilled. With the T-square draw a pencil line $\frac{5}{32}$ inch above the top border line at the right-hand end. This line should be about 3 inches long. At a distance of $\frac{5}{32}$ inch above this line draw another line of about the same length. These are the guide lines for the word *PLATE I*. The letters should be pencilled free hand and the student may use the 60-degree guide lines if he desires.

The guide lines of the date, name and address are similarly drawn in the lower margin. The date of completing the drawing should be placed under *Fig. 3* and the name and address at the right under *Fig. 4*. The street address is unnecessary. It is a good plan to draw lines $\frac{5}{32}$ inch apart on a separate sheet of paper and pencil the letters in order to know just how much space each word will require. The insertion of the words "*Fig. 1*," "*Fig. 2*," etc., is optional with the student. He may leave them out if he desires; but we would advise him to do this extra lettering for the practice and for convenience in reference. First draw with the T-square two parallel lines $\frac{5}{32}$ inch apart under each exercise; the lower line being $\frac{1}{16}$ inch above the horizontal center line or above the lower border line.

Inking. After all of the pencilling of *PLATE I* has been completed the exercises should be inked. The pen should first be examined to make sure that the nibs are clean, of the same length and come together evenly. To fill the pen with ink use an ordinary steel pen or the quill in the bottle, if Higgin's Ink is used. Dip the quill or pen into the bottle and then inside between the nibs of the line pen. The ink will readily flow from the quill into the space between the nibs as soon as it is brought in contact. Do not fill the pen too full, if the ink fills about $\frac{1}{4}$ the distance to the adjusting screw it usually will be sufficient. If the filling has been carefully done it will not be necessary to wipe the outsides of the blades. However, any ink on the outside should be wiped off with a soft cloth or a piece of chamois.

The pen should now be tried on a separate piece of paper in order that the width of the line may be adjusted. In the first work where no shading is done, a firm distinct line should be used. The beginner should avoid the extremes; a very light line makes

the drawing have a weak, indistinct appearance, and very heavy lines detract from the artistic appearance and make the drawing appear heavy.

In case the ink does not flow freely, wet the finger and touch it to the end of the pen. If it then fails to flow, draw a slip of thin paper between the nibs (thus removing the dried ink) or clean thoroughly and fill. Never lay the pen aside without cleaning.

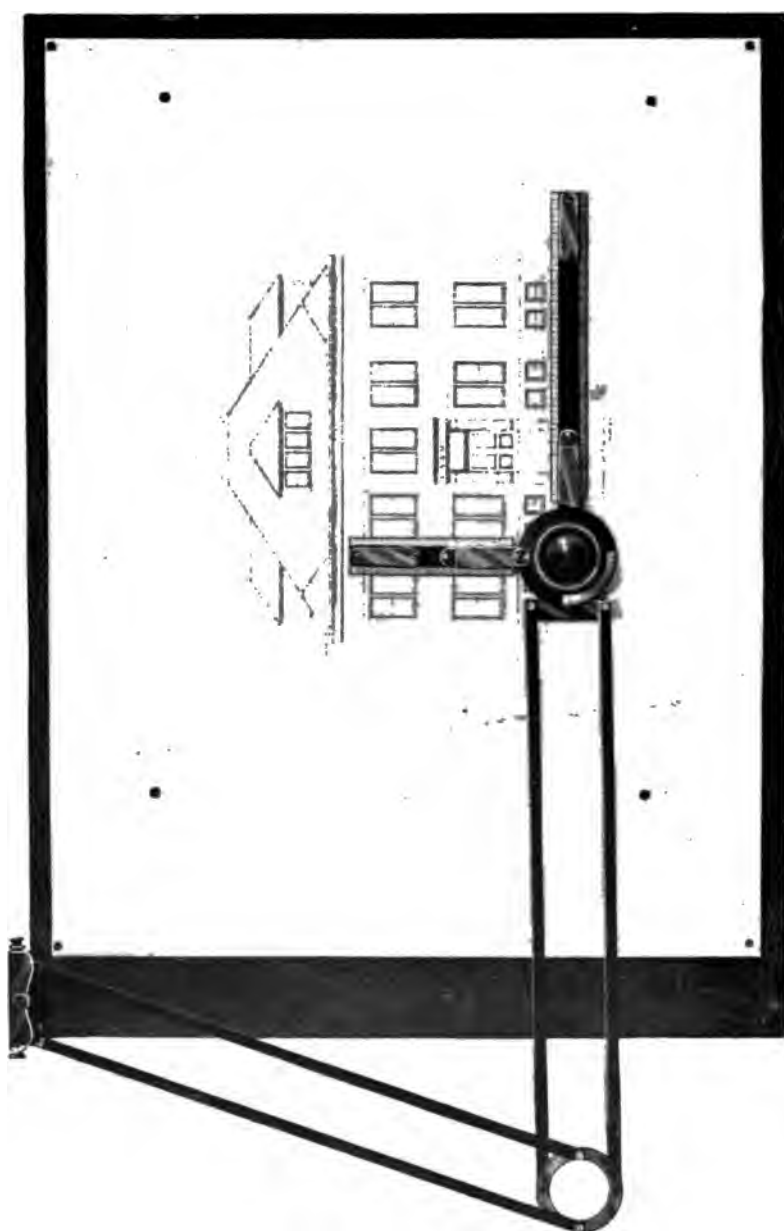
In ruling with the line pen it should be held firmly in the right hand almost perpendicular to the paper. If grasped too firmly the width of the line may be varied and the draftsman soon becomes fatigued. The pen is usually held so that the adjusting screw is away from the T-square, triangles, etc. Many draftsmen incline the pen slightly in the direction in which it is moving.

To ink *Fig. 1*, place the T-square with the head at the working edge as in pencilling. First ink all of the horizontal lines moving the T-square from A to D. In drawing these lines considerable care is necessary; both nibs should touch the paper and the pressure should be uniform. Have sufficient ink in the pen to finish the line as it is difficult for a beginner to stop in the middle of the line and after refilling the pen make a smooth continuous line. While inking the lines A, E, F, G, H, I, etc., greater care should be taken in starting and stopping than while pencilling. Each line should start *exactly* in the pencil line A D and stop in the line B C. The lines A D and B C are inked, using the triangle and T-square.

Fig. 2 is inked in the same manner as it was pencilled; the lines being drawn, sliding the triangle along the T-square in the successive positions.

In inking *Fig. 3*, the same care is necessary as with the preceding, and after the oblique lines are inked the border lines are finished. In *Fig. 4* the border lines should be inked in first and then the border lines of the plate. The border lines should be quite heavy as they give the plate a better appearance. The intersections should be accurate, as any running over necessitates erasing.

The line pen may now be cleaned and laid aside. It can be



THE UNIVERSAL DRAFTING MACHINE.

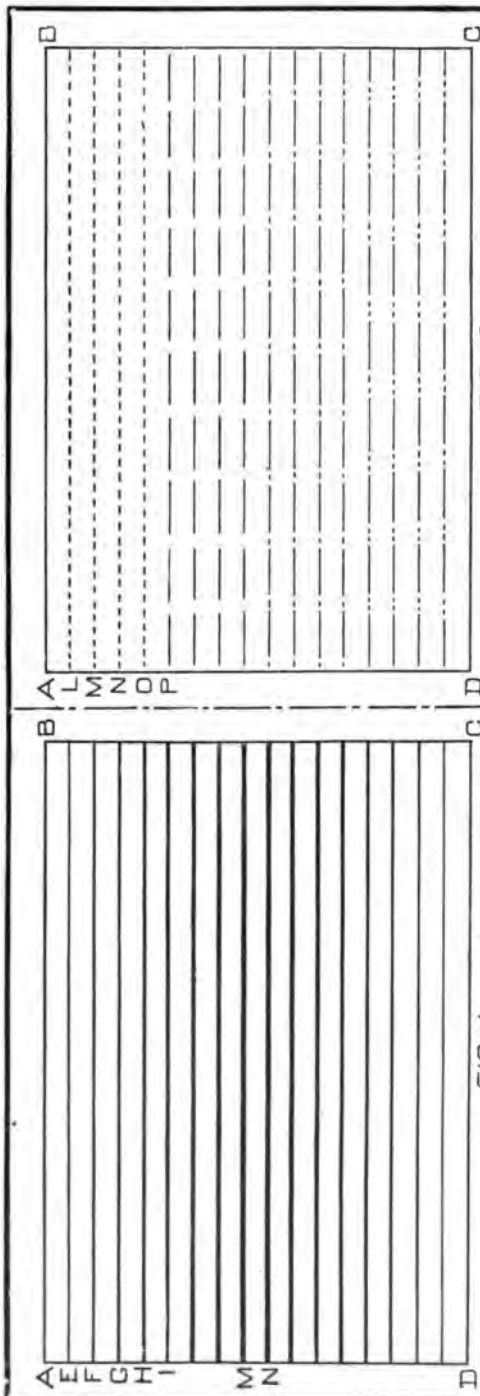
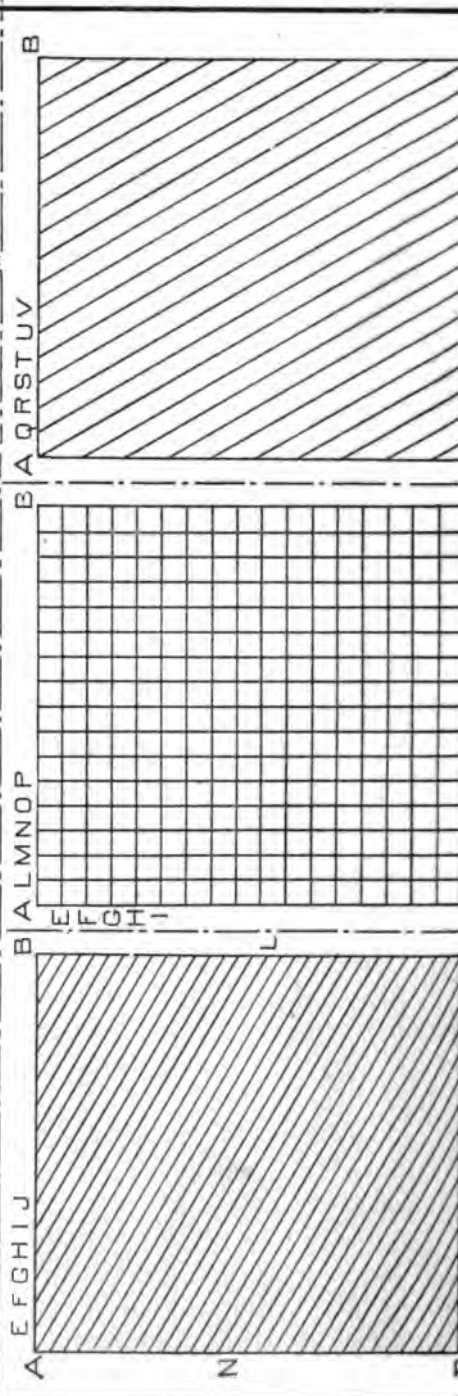


FIG. 2



cleaned by drawing a strip of blotting paper between the ribs or by means of a piece of cloth or chamois. The lettering should be done free-hand using a steel pen. If the pen is very fine, accurate work may be done but the pen is likely to catch in the paper, especially if the paper is rough. A coarser pen will make broader lines but is on the whole preferable. Gillott's 404 is as fine a pen as should be used. After inking *Fig. 4*, the plate number, date and name should be inked, also free-hand. After inking the words "*Fig. 1*," "*Fig. 2*," etc., all pencil lines should be erased. In the finished drawing there should be no center lines, construction lines or letters other than those in the name, date, etc.

The sheet should be cut to a size of 11 inches by 15 inches, the dash line outside the border line of *PLATE I* indicating the edge.

PLATE II.

Pencilling. The drawing paper used for *PLATE II* should be laid out as described with *PLATE I*, that is, the border lines, center line and rectangles for *Figs. 1* and *2*. To lay out *Figs. 3, 4* and *5* proceed as follows: Draw a line with the T-square parallel to the horizontal center line and $\frac{1}{4}$ inch below it. Also draw another similar line $4\frac{1}{2}$ below the center line. The two lines will form the top and bottom of *Figs. 3, 4* and *5*. Now measure off $2\frac{1}{4}$ inches on either side of the center on the horizontal center line and call the points Y and Z. On either side of Y and Z and at a distance of $\frac{1}{4}$ inch draw vertical parallel lines. Now draw a vertical line A D, $4\frac{1}{4}$ inches from the line Y and a vertical line B C $4\frac{1}{4}$ inches from the line Z. We now have three rectangles each 4 inches broad and $4\frac{1}{4}$ inches high. *Figs. 1* and *2* are pencilled in exactly the same way as was *Fig. 1* of *PLATE I*, that is, horizontal lines are drawn $\frac{1}{4}$ inch apart.

Fig. 3 is an exercise to show the use of a 60-degree triangle with a T-square. Lay off the distances A E, E F, F G, G H, etc., to B each $\frac{1}{4}$ inch. With the 60 degree triangle resting on the upper edge of the T-square, draw lines through these points, E, F, G, H, I, J, etc., forming an angle of 30 degrees with the horizontal. The last line drawn will be A L. In drawing these lines move the pencil from A B to B C. Now find the distance

between the lines on the vertical B L and mark off these distances on the line B C commencing at L. Continue the lines from A L to N C. Commencing at N mark off distances on A D equal to those on B C and finish drawing the oblique lines.

Fig. 4 is an exercise for intersection. Lay off distances of $\frac{1}{4}$ inch on A B and A D. With the T-square draw fine pencil lines through the points E, F, G, H, I, etc., and with the T-square and triangle draw vertical lines through the points L, M, N, O, P, etc. In drawing this figure draw every line exactly through the points indicated as the symmetrical appearance of the small squares can be attained only by accurate pencilling.

The oblique lines in *Fig. 5* form an angle of 60 degrees with the horizontal. As in *Figs. 3* and *4* mark off the line A B in divisions of $\frac{1}{4}$ inch and draw with the T-square and 60-degree triangle the oblique lines through these points of division moving the pencil from A B to B C. The last line thus drawn will be A L. Now mark off distances of $\frac{1}{4}$ inch on C D beginning at L. The lines may now be finished.

Inking. *Fig. 1* is designed to give the beginner practice in drawing lines of varying widths. The line E is first drawn. This line should be rather fine but should be clear and distinct. The line F should be a little wider than E; the greater width being obtained by turning the adjusting screw from one-quarter to one-half a turn. The lines G, H, I, etc., are drawn: each successive line having greater width. M and N should be the same and quite heavy. From N to D the lines should *decrease* in width. To complete the inking of *Fig. 1*, draw the border lines. These lines should have about the same width as those in *PLATE I*.

In *Fig. 2* the first four lines should be dotted. The dots should be uniform in length (about $\frac{1}{16}$ inch) and the spaces also uniform (about $\frac{1}{32}$ inch). The next four lines are dash lines similar to those used for dimensions. These lines should be drawn with dashes about $\frac{3}{4}$ inch long and the lines should be fine, yet distinct.

The following four lines are called dot and dash lines. The dashes are about $\frac{3}{4}$ inch long and a dot between as shown. In the regular practice of drafting the length of the dashes depends upon the size of the drawing — $\frac{1}{2}$ inch to 1 inch being common. The last four lines are similar, two dots being used between the

dashes. After completing the dot and dash lines, draw the border lines of the rectangle as before.

In inking *Fig. 3*, the pencil lines are followed. Great care should be exercised in starting and stopping. The lines should begin in the border lines and the end should not run over.

The lines of *Fig. 4* must be drawn carefully, as there are so many intersections. The lines in this figure should be lighter than the border lines. If every line does not coincide with the points of division L, M, N, O, P, etc., some will appear farther apart than others.

Fig. 5 is similar to *Fig. 3*, the only difference being in the angle which the oblique lines make with the horizontal.

After completing the five figures draw the border lines of the plate and then letter the plate number, date and name, and the figure numbers, as in *PLATE I*. The plate should then be cut to the required size, 11 inches by 15 inches.

PLATE III.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE III* are laid out in the same manner as were those of *PLATE II*. To draw the squares for the six figures, proceed as follows:

Measure off two inches on either side of the vertical center line and draw light pencil lines through these points parallel to the vertical center line. These lines will form the sides A D and B C of *Figs. 2* and *5*. Parallel to these lines and at a distance of $\frac{1}{2}$ inch draw similar lines to form the sides B C of *Figs. 1* and *4* and A D of *Figs. 3* and *6*. The vertical sides A D of *Figs. 1* and *4* and B C of *Figs. 3* and *6* are formed by drawing lines perpendicular to the horizontal center line at a distance of $6\frac{1}{2}$ inches from the center.

The horizontal sides D C of *Figs. 1, 2* and *3* are drawn with the T-square $\frac{1}{2}$ inch above the horizontal center line. To draw the top lines of these figures, draw (with the T-square) a line $4\frac{1}{2}$ inches above the horizontal center line. The top lines of *Figs. 4, 5* and *6* are drawn $\frac{1}{2}$ inch below the horizontal center line. The squares are completed by drawing the lower lines D C, $4\frac{1}{2}$ inches below the horizontal center line. The figures of *PLATES I* and *II*

were constructed in rectangles; the exercises of *PLATE III* are, however, drawn in squares, having the sides 4 inches long.

In drawing *Fig. 1*, first divide *A D* and *A B* (or *D C*) into 4 equal parts. As these lines are four inches long, each length will be 1 inch. Now draw horizontal lines through *E*, *F* and *G* and vertical lines through *L*, *M* and *N*. These lines are shown dotted in *Fig. 1*. Connect *A* and *B* with the intersection of lines *E* and *M*, and *A* and *D* with the intersection of lines *F* and *L*. Similarly draw *D J*, *J C*, *I B* and *I C*. Also connect the points *P*, *O*, *I* and *J* forming a square. The four diamond shaped areas are formed by drawing lines from the middle points of *A D*, *A B*, *B C* and *D C* to the middle points of lines *A P*, *A O*, *O B*, *I B* etc., as shown in *Fig. 1*.

Fig. 2 is an exercise of straight lines. Divide *A D* and *A B* into four equal parts and draw horizontal and vertical lines as in *Fig. 1*. Now divide these dimensions, *A L*, *M N*, etc. and *E F*, *G B* etc. into four equal parts (each $\frac{1}{4}$ inch). Draw light pencil lines with the T-square and triangle as shown in *Fig. 2*.

In *Fig. 3*, divide *A B* and *A D* into eight parts, each length being $\frac{1}{2}$ inch. Through the points *H*, *I*, *J*, *K*, *L*, *M* and *N* draw vertical lines with the triangle. Through *O*, *P*, *Q*, *R*, *S*, *T* and *U* draw horizontal lines with the T-square. Now draw lines connecting *O* and *H*, *P* and *I*, *Q* and *J*, etc. These lines can be drawn with the 45-degree triangle, as they form an angle of 45 degrees with the horizontal. Starting at *N* draw lines from *A B* to *B C* at an angle of 45 degrees. Also draw lines from *A D* to *D C* through the points *O*, *P*, *Q*, *R*, etc., forming angles of 45 degrees with *D C*.

Fig. 4 is drawn with the compasses. First draw the diagonals *A C* and *D B*. With the T-square draw the line *E H*. Now mark off on *E H* distances of $\frac{1}{4}$ inch. With the compasses set so that the point of the lead is 2 inches from the needle point, describe the circle passing through *E*. With *H* as a center draw the arcs *F G* and *I J* having a radius of $1\frac{3}{4}$ inches. In drawing these arcs be careful not to go beyond the diagonals, but stop at the points *F* and *G* and *I* and *J*. Again with *H* as the center and a radius of $1\frac{1}{2}$ inches draw a circle. The arcs *K L* and *M N* are drawn in the same manner as were arcs *F G* and *I J*; the

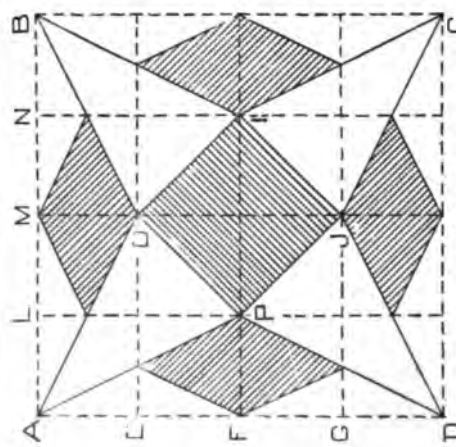


FIG. 1

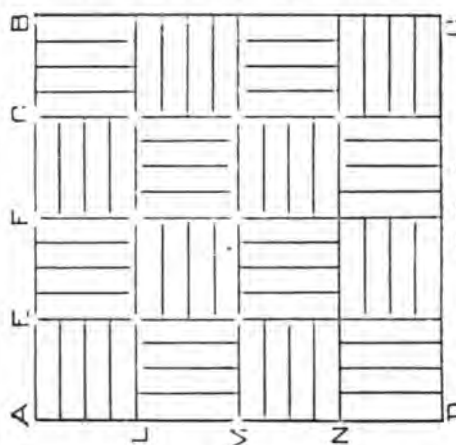


FIG. 2

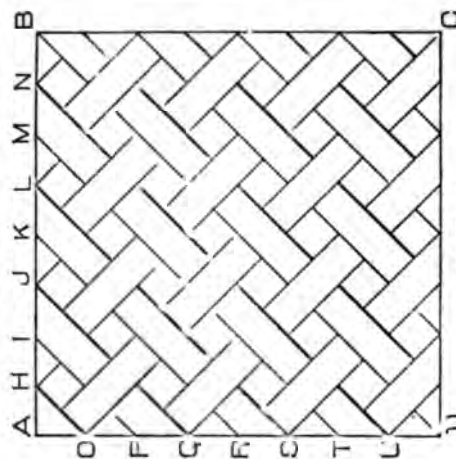


FIG. 3

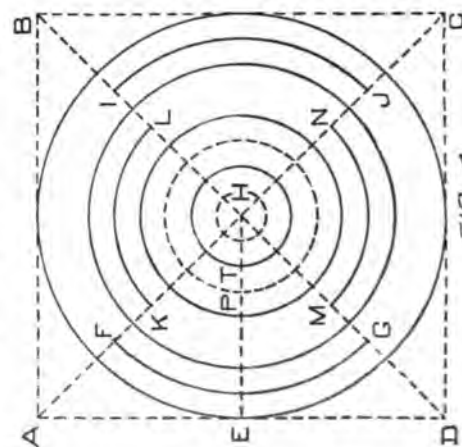


FIG. 4

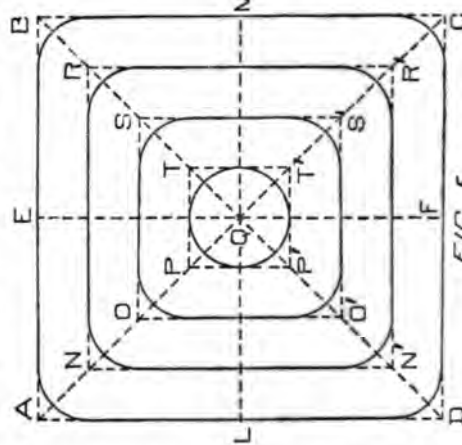


FIG. 5

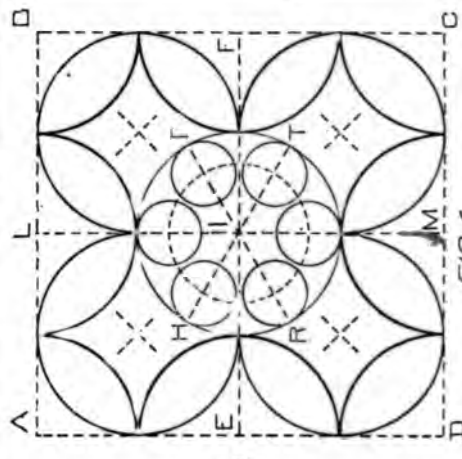


FIG. 6

radius being $1\frac{1}{4}$ inches. Now draw circles, with H as the center, of 1 , $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ inch radius, passing through the points P, T, etc.

Fig. 5 is an exercise with the line pen and compasses. First draw the diagonals A C and D B, the horizontal line L M and the vertical line E F passing through the center Q. Mark off distances of $\frac{1}{2}$ inch on L M and E F and draw the lines N N' O O' and N R, O S, etc., through these points, forming the squares N R R' N', O S S' O', etc. With the bow pencil adjusted so that the distance between the pencil point and the needle point is $\frac{1}{2}$ inch draw the arcs having centers at the corners of the squares. The arc whose center is N will be tangent to the lines A L and A E and the arc whose center is O will be tangent to N N' and N R. Since P T, T T', T' P' and P' P are each 1 inch long and form the square, the arcs drawn with Q as a center will form a circle.

To draw *Fig. 6*, first draw the center lines E F and L M. Now find the centers of the small squares A L I E, L B F I etc. Through the center I draw the construction lines H I T and R I P forming angles of 30 degrees with the horizontal. Now adjust the compasses to draw circles having a radius of one inch. With I as a center, draw the circle H P T R. With the same radius (one inch) draw the arcs with centers at A, B, C and D. Also draw the semi-circles with centers at L, F, M and E. Now draw the arcs as shown having centers at the centers of the small squares A L I E, L B F I, etc. To locate the centers of the six small circles within the circle H P T R, draw a circle with a radius of $\frac{11}{16}$ inch and having the center in I. The small circles have a radius of $\frac{5}{16}$ inch.

Inking. In inking this plate, the outlines of the squares of the various figures are inked only in *Figs. 2 and 3*. In *Fig. 1* the only lines to be inked are those shown in **full** lines in *PLATE III*. First ink the star and then the square and diamonds. The cross hatching should be done *without* measuring the distance between the lines and without the aid of any cross hatching device as this is an exercise for practice. The lines should be about $\frac{1}{16}$ inch apart. After inking erase all construction lines.

In inking *Fig. 2* be careful not to run over lines. Each line should coincide with the pencil line. The student should

first ink the horizontal lines L, M and N and the vertical lines E, F and G. The short lines should have the same width but the border lines, A B, B C, C D and D A should be a little heavier.

Fig. 3 is drawn entirely with the 45-degree triangle. In inking the oblique lines make P I, R K, T M, etc., a light distinct line. The alternate lines O H, Q J, S L, etc., should be somewhat heavier. All of the lines which slope in the opposite direction are light. After inking *Fig. 3* all horizontal and vertical lines (except the border lines) should be erased. The border lines should be slightly heavier than the light oblique lines.

The only instrument used in inking *Fig. 4* is the compasses. In doing this exercise adjust the legs of the compasses so that the pen will always be perpendicular to the paper. If this is not done both nibs will not touch the paper and the line will be ragged. In inking the arcs, see that the pen stops *exactly* at the diagonals. The circle passing through T and the small inner circle should be dotted as shown in *PLATE III*. After inking the circles and arcs erase the construction lines that are without the outer circles but leave in *pencil* the diagonals inside the circle.

In *Fig. 5* draw all arcs *first* and then draw the straight lines meeting these arcs. It is much easier to draw straight lines meeting arcs, or tangent to them, than to make the arcs tangent to straight lines. As this exercise is difficult, and in all mechanical and machine drawing arcs and tangents are frequently used we advise the beginner to draw this exercise several times. Leave all construction lines in pencil.

Fig. 6, like *Fig. 4*, is an exercise with compasses. If *Fig. 6* has been laid out accurately in pencil, the inked arcs will be tangent to each other and the finished exercise will have a good appearance. If, however, the distances were not accurately measured and the lines carefully drawn the inked arcs will not be tangent. The arcs whose centers are L, F, M and E and A, B, C and D should be heavier than the rest. The small circles may be drawn with the bow pen. After inking the arcs all construction lines should be erased.

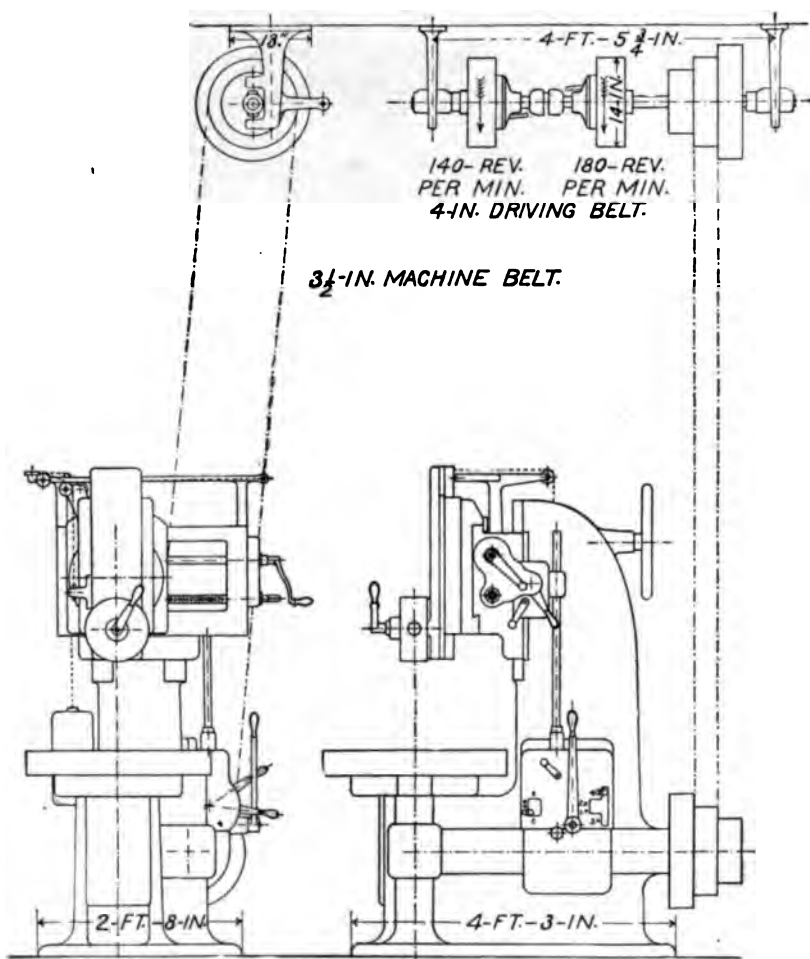


DIAGRAM FOR INSTALLING A 30-INCH VERTICAL TURRET MACHINE.
 Warner and Swasey.

MECHANICAL DRAWING.

PART II.

GEOMETRICAL DEFINITIONS.

A **point** is used for marking position; it has neither **length**, breadth nor thickness.

A **line** has length only; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same **direction** throughout. It is the shortest distance between any two of its points.

A *curved line* is one that is constantly changing in **direction**. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are equally distant from each other **at all points**.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

Lines are *perpendicular* to each other, if when they cross, the four angles formed are equal. If they meet and form two equal angles they are perpendicular.

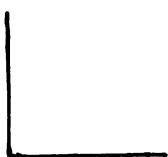
An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T square, when the head of the T square is resting against the left-hand edge of the board, are called horizontal lines. Those drawn at right angles or perpendicular to the edge of the T square are called vertical.

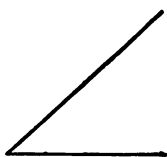
If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection*.

ANGLES.

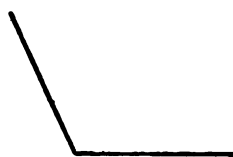
An **angle** is formed when two straight lines meet. An angle is often defined as being the difference in direction of two straight lines. The lines are called the *sides* and the point of meeting is called the *vertex*. The size of an angle depends upon the amount of divergence of the sides and is independent of the length of these lines.



RIGHT ANGLE.



ACUTE ANGLE.



OBTUSE ANGLE.

If one straight line meet another and the angles thus formed are equal they are **right angles**. When two lines are perpendicular to each other the angles formed are right angles.

An **acute angle** is less than a right angle.

An **obtuse angle** is greater than a right angle.

SURFACES.

A **surface** is produced by the motion of a line; it has two dimensions, — length and breadth.

A **plane figure** is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure*.

TRIANGLES.

A **triangle** is a figure enclosed by three straight lines. It is a polygon of three sides. The bounding lines are the *sides*, and the points of intersection of the sides are the *vertices*. The *angles* of a triangle are the angles formed by the sides.

A **right-angled triangle**, often called a *right triangle*, is one that has a right angle.

An **acute-angled triangle** is one that has all of its angles acute.

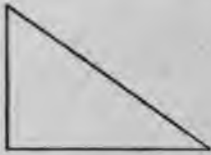
An **obtuse-angled triangle** is one that has an obtuse angle.

In an **equilateral triangle** all of the sides are equal.

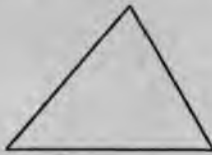
If all of the *angles* of a triangle are equal, the figure is called an **equiangular** triangle.

A triangle is called **scalene**, when no two of its sides are equal.

In an **isosceles** triangle two of the sides are equal.



RIGHT ANGLED TRIANGLE.



ACUTE ANGLED TRIANGLE.



OBTUSE ANGLED TRIANGLE.

The *base* of a triangle is the lowest side ; however, any side may be taken as the base. In an isosceles triangle the side which is not one of the equal sides is usually considered the base.

The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.



EQUILATERAL TRIANGLE.



ISOSCELES TRIANGLE.



SCALENE TRIANGLE.

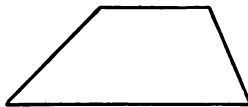
QUADRILATERALS.

A **quadrilateral** is a plane figure bounded by four straight lines.

The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.



QUADRILATERAL.



TRAPEZOID.



PARALLELOGRAM.

A **trapezium** is a quadrilateral, no two of whose sides are parallel.

A **trapezoid** is a quadrilateral having two sides parallel.

The *bases* of a trapezoid are its parallel sides. The *altitude* is the perpendicular distance between the bases.

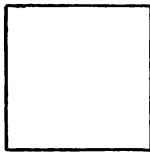
A **parallelogram** is a quadrilateral whose opposite sides are parallel.

The *altitude* of a parallelogram is the perpendicular distance between the bases which are the parallel sides.

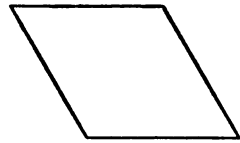
There are four kinds of parallelograms:



RECTANGLE.



SQUARE.



RHOMBUS.

A **rectangle** is a parallelogram, all of whose angles are right angles. The opposite sides are equal.

A **square** is a rectangle, all of whose sides are equal.

A **rhombus** is a parallelogram which has four equal sides; but the angles are not right angles.

A **rhomboid** is a parallelogram whose adjacent sides are unequal; the angles are not right angles.

POLYGONS.

A **polygon** is a plane figure bounded by straight lines.

The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A **triangle** is a polygon of *three* sides.

A **quadrilateral** is a polygon of *four* sides.

A **pentagon** is a polygon of *five* sides.

A **hexagon** is a polygon of *six* sides.

A **heptagon** is a polygon of *seven* sides.

An **octagon** is a polygon of *eight* sides.

A **decagon** is a polygon of *ten* sides.

A **dodecagon** is a polygon of *twelve* sides.

An *equilateral* polygon is one all of whose sides are equal.

An *equiangular* polygon is one all of whose angles are equal.

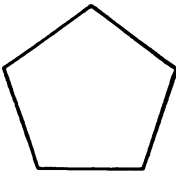
A *regular polygon* is one all of whose angles are equal and all of whose sides are equal.

CIRCLES.

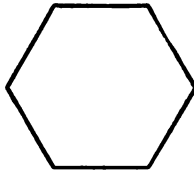
A **circle** is a plane figure bounded by a curved line, every point of which is equally distant from a point within called the center.

The curve which bounds the circle is called the **circumference**. Any portion of the circumference is called an *arc*.

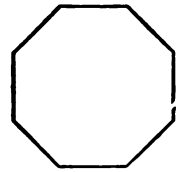
The **diameter** of a circle is a straight line drawn through the center and terminating in the circumference. A **radius** is a straight line joining the center with the circumference. It has a length equal to one half the diameter. All radii (plural of radius) are equal and all diameters are equal since a diameter equals two radii.



PENTAGON.



HEXAGON.

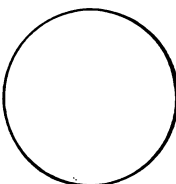


OCTAGON.

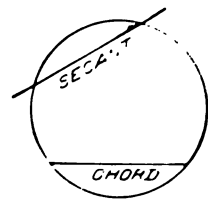
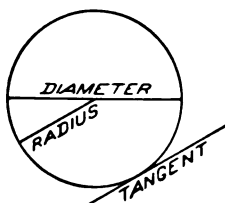
An arc equal to one-half the circumference is called a *semi-circumference*, and an arc equal to one-quarter of the circumference is called a *quadrant*. A quadrant may mean the sector, arc or angle.

A **chord** is a straight line joining the extremities of an arc. It is a line drawn across a circle that does not pass through the center.

A **secant** is a straight line which intersects the circumference in two points.



CIRCLE.

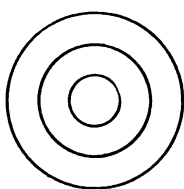
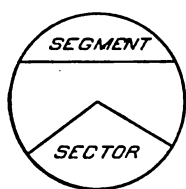


A **tangent** is a straight line which touches the circumference at only one point. It does not intersect the circumference. The point at which the tangent touches the circumference is called the *point of tangency* or *point of contact*.

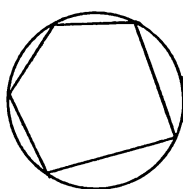
A **sector** of a circle is the portion or area included between an arc and two radii drawn to the extremities of the arc.

A **segment** of a circle is the area included between an arc and its chord.

Circles are **tangent** when the circumferences touch at only one point and are **concentric** when they have the same center.



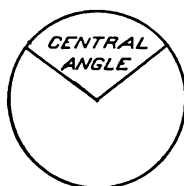
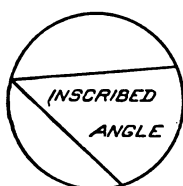
CONCENTRIC CIRCLES.



INSCRIBED POLYGON

An **inscribed angle** is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc.

A **central angle** is an angle whose vertex is at the center of the circle and whose sides are radii.



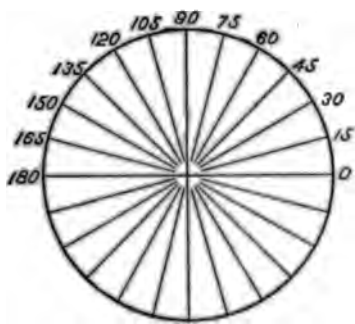
An **inscribed polygon** is one whose vertices lie in the circumference and whose sides are chords.

MEASUREMENT OF ANGLES.

To measure an angle describe an arc with the center at the vertex of the angle and having any convenient radius. The portion of the arc included between the sides of the angle is the measure of the angle. If the arc has a constant radius the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

In order that the size of an angle or arc may be stated with-

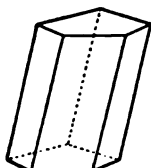
out saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called degrees. Thus we can say that an angle contains 45 degrees, which means that it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute is divided into 60 equal parts called *seconds*. Angles and arcs are usually measured by means of an instrument called a protractor which has already been explained.



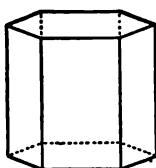
SOLIDS.

A **polyedron** is a solid bounded by planes. The bounding planes are called the *faces* and their intersections *edges*. The intersections of the edges are called *vertices*.

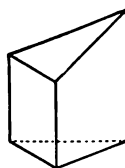
A polygon having four faces is called a **tetraedron**; one having six faces a **hexaedron**; of eight faces an **octaedron**; of twelve faces a **dodecaedron**, etc.



PRISM.



RIGHT PRISM.



TRUNCATED PRISM.

A **prism** is a polyedron, of which two opposite faces, called *bases*, are equal and parallel; the other faces, called *lateral faces* are parallelograms.

The area of the lateral faces is called the *lateral area*.

The *altitude* of a prism is the perpendicular distance between the bases.

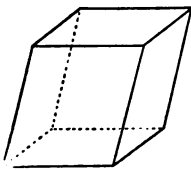
Prisms are *triangular*, *quadrangular*, etc., according to the shape of the base.

A **right prism** is one whose lateral edges are perpendicular to the bases.

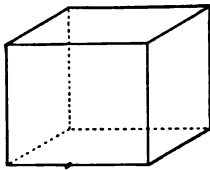
A **regular prism** is a right prism having regular polygons for bases.

A **parallelopiped** is a prism whose bases are parallelograms. If the edges are all perpendicular to the bases it is called a **right parallelopiped**.

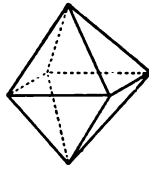
A **rectangular parallelopiped** is a right parallelopiped whose bases are rectangles ; all the faces are rectangles.



PARALLELOPIPED.



RECTANGULAR PARALLELOPIPED.



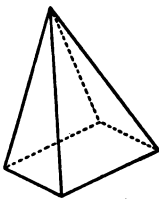
OCTAEDRON.

A **cube** is a rectangular parallelopiped all of whose faces are squares.

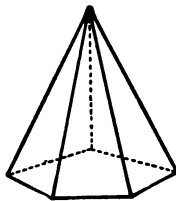
A **truncated prism** is the portion of a prism included between the base and a plane not parallel to the base.

PYRAMIDS.

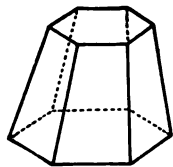
A **pyramid** is a polyhedron one face of which is a polygon (called the base) and the other faces are triangles having a common vertex.



PYRAMID.



REGULAR PYRAMID.



FRUSTUM OF PYRAMID.

The vertices of the triangles form the *vertex* of the pyramid.

The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

A pyramid is called **triangular**, **quadrangular**, etc., according to the shape of the base.

A **regular pyramid** is one whose base is a regular polygon

and whose vertex lies in the perpendicular erected at the center of the base.

A **truncated pyramid** is the portion of a pyramid included between the base and a plane not parallel to the base.

A **frustum** of a pyramid is the solid included between the base and a plane parallel to the base.

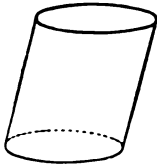
The *altitude* of a frustum of a pyramid is the perpendicular distance between the bases.

CYLINDERS.

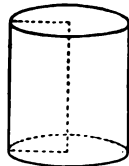
A **cylindrical surface** is a curved surface generated by the motion of a straight line which touches a curve and continues parallel to itself.

A **cylinder** is a solid bounded by a cylindrical surface and two parallel planes intersecting this surface.

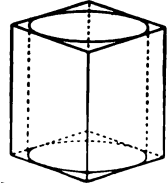
The parallel faces are called *bases*.



CYLINDER.



RIGHT CYLINDER.



INSCRIBED CYLINDER.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A **circular cylinder** is a cylinder whose base is a circle.

A **right cylinder** or a *cylinder of revolution* is a cylinder generated by the revolution of a rectangle about one side as an axis.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder.

The cylindrical area is called the *lateral area*. The *total area* is the area of the bases added to the lateral area.

CONES.

A **conical surface** is a curved surface generated by the motion of a straight line, one point of which is fixed and the end or ends of which move in a curve.

A **cone** is a solid bounded by a conical surface and a plane which cuts the conical surface.

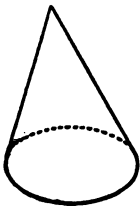
The plane is called the *base* and the curved surface the lateral area.

The *vertex* is the fixed point.

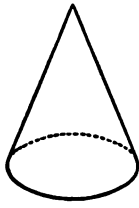
The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is a straight line from the vertex to the perimeter of the base.

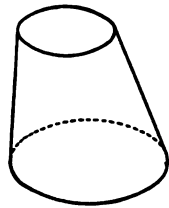
A **circular cone** is a cone whose base is a circle.



CONE.



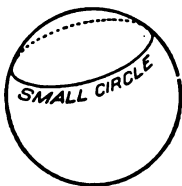
RIGHT CIRCULAR CONE.



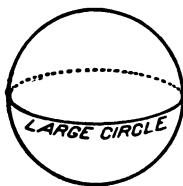
FRUSTUM OF CONE.

A **right circular cone** or **cone of revolution** is a cone whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the perpendicular sides as an axis.

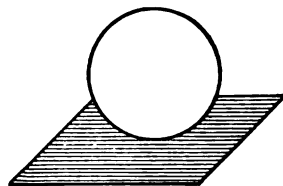
A **frustum** of a cone is the solid included between the base and a plane parallel to the base.



SPHERE.



SPHERE.



TANGENT PLANE.

The *altitude* of a frustum of a cone is the perpendicular distance between the bases.

SPHERES.

A **sphere** is a solid bounded by a curved surface, every point of which is equally distant from a point within called the center.

The *radius* of a sphere is a straight line drawn from the

center to the surface. The *diameter* is a straight line drawn through the center and having its extremities in the surface.

A sphere may be generated by the revolution of a semi-circle about its diameter as an axis.

An *inscribed polyedron* is a polyedron whose vertices lie in the surface of the sphere.

An *circumscribed polyedron* is a polyedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of a sphere.

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center.

A sphere is *tangent* to a plane when the plane touches the surface in only one point. A plane perpendicular to the extremity of a radius is tangent to the sphere.

CONIC SECTIONS.

If a plane intersects a cone the geometrical figures thus formed are called conic sections. A plane perpendicular to the base and passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base the intersection of the plane and conical surface will be the circumference of a circle.

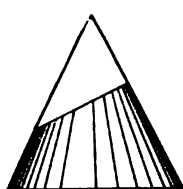


Fig. 1.



Fig. 2.

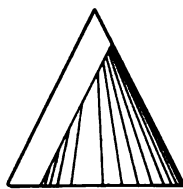


Fig. 3.

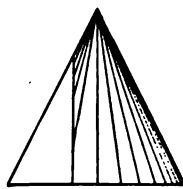


Fig. 4.

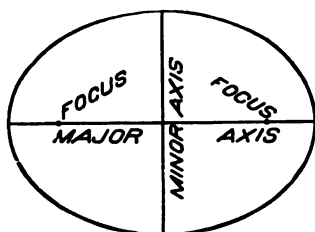
Ellipse. The ellipse is a curve formed by the intersection of a plane and a cone, the plane being oblique to the axis but not cutting the base. If a plane is passed through a cone as shown in Fig. 1 or through a cylinder as shown in Fig 2, the curve of intersection will be an ellipse. An ellipse may be defined as being *a curve generated by a point moving in a plane, the sum of the distances of the point to two fixed points being always constant.*

The two fixed points are called the **foci** and lie on the

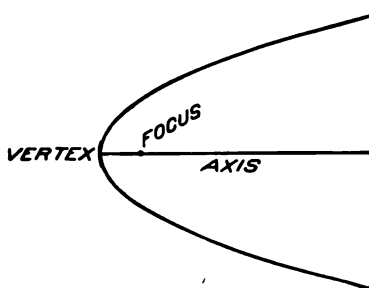
longest line that can be drawn in the ellipse. One of these points is called a *focus*.

The longest line that can be drawn in an ellipse is called the **major axis** and the shortest line, passing through the center, is called the **minor axis**. The minor axis is perpendicular to the middle point of the major axis and the point of intersection is called the center.

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.



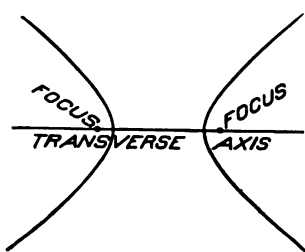
ELLIPSE.



PARABOLA.

Parabola. The parabola is a curve formed by the intersection of a cone and a plane parallel to an element as shown in Fig. 3. The curve is not a closed curve. The branches approach parallelism.

A parabola may be defined as being a curve every point of which is equally distant from a line and a point.



HYPERBOLA.

The point is called the **focus** and the given line the **directrix**. The line perpendicular to the directrix and passing through the focus is the **axis**. The intersection of the axis and the curve is the **vertex**.

Hyperbola. This curve is formed by the intersection of a plane and a cone, the plane being parallel to the axis of the cone as shown in Fig. 4. Like the parabola, the curve is not a closed curve; the branches constantly diverge.

An hyperbola is defined as being a plane curve such that the difference of the distances from any point in the curve to two fixed points is equal to a given distance.

The two fixed points are the **foci** and the line passing through them is the **transverse axis**.

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular co-ordinates. This curve is constructed as follows: In Fig. 5, O X and O Y are the two co-ordinates drawn at right angles to each other. These lines are also called axes or asymptotes. Assume A to be a known point on the curve. In drawing this curve for the theoretical indicator card, this point A is the point of cut-off.

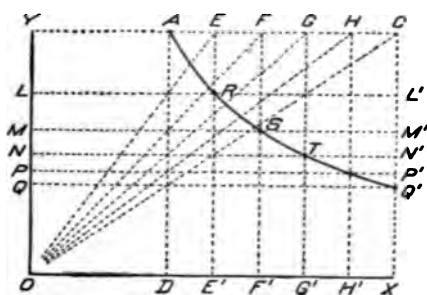


Fig. 5.

Draw AC parallel to OX and AD perpendicular to OX. Now mark off any convenient points on AC such as E, F, G, and H; and through these points draw EE', FF', GG', and HH' perpendicular to OX. Connect E, F, G, H and C with O. Through the points of intersection of the oblique lines and the vertical line AD draw the horizontal lines LL', MM', NN', PP' and QQ'. The first point on the curve is the assumed point A, the second point is R, the intersection of LL' and EE'. The third is the intersection S of MM' and FF'; the fourth is the intersection T of NN' and GG'. The other points are found in the same way.

In this curve the products of the co-ordinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

ODONTOIDAL CURVES.

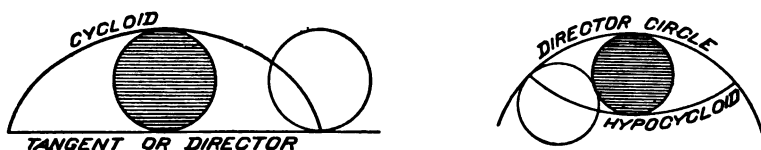
The outlines of the teeth of gears must be drawn accurately because the smoothness of running depends upon the shape of the teeth. The two classes of curves generally employed in drawing gear teeth are the cycloidal and involute.

Cycloid. The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle.

The rolling circle is called the *describing* or *generating circle*

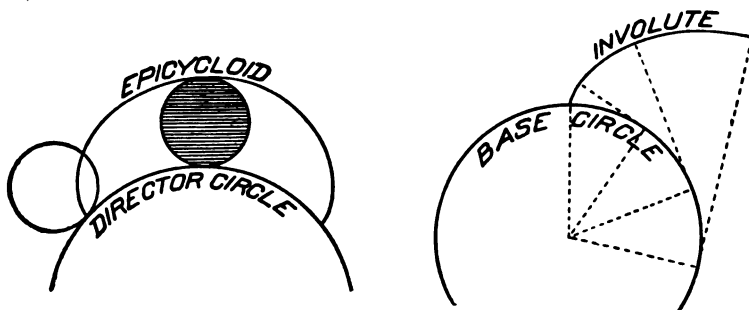
and the point, the *describing* or *generating point*. The tangent along which the circle rolls is called the *director*.

In order that the curve may be a true cycloid the circle must roll without any slipping.



Epicycloid. If the generating circle rolls upon the *outside* of an arc or circle, called the *director circle*, the curve thus generated is called an epicycloid. The method of drawing this curve is the same as that for the cycloid.

Hypocycloid. In case the generating circle rolls upon the *inside* of an arc or circle, the curve thus generated is called the hypocycloid. The circle upon which the generating circle rolls is



called the *director circle*. If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.

Involute. If a thread or fine wire is wound around a cylinder or circle and then unwound, the end will describe a curve called an involute. The involute may be defined as being *a curve generated by a point in a tangent rolling on a circle known as the base circle*.

The construction of the ellipse, parabola, hyperbola and odontoidal curves will be taken up in detail with the plates.

PLATE IV.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE IV* should be laid out in the same manner as were those for *PLATE I*. There are to be six figures on this plate and to facilitate the laying out of the work, the following lines should be drawn: measure off $2\frac{1}{4}$ inches on both sides of the vertical center line and through these points draw vertical lines as shown in dot and dash lines on *PLATE IV*. In these six spaces the six figures are to be drawn, the student placing them in the centers of the spaces so that they will present a good appearance. In locating the figures, they should be placed a little above the center so that there will be sufficient space below to number the problem.

The figures of the problems should first be drawn lightly in pencil and after the entire plate is completed the lines should be inked. In pencilling, all intersections must be formed with great care as the accuracy of the results depends upon the pencilling. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

GEOMETRICAL PROBLEMS.

The following problems are of great importance to the mechanical draughtsman. The student should solve them with care; he should not do them blindly, but should understand them so that he can apply the principles in later work.

PROBLEM I. To Bisect a Given Straight Line.

Draw the horizontal straight line *A C* about 3 inches long. With the extremity *A* as a center and any convenient radius (about 2 inches) describe arcs above and below the line *A C*. With the other extremity *C* as a center and with the same radius draw short arcs above and below *A C* intersecting the first arcs at *D* and *E*. The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line *D E* passing through the intersections *D* and *E*. This line cuts the line *A C* at *F* which is the middle point.

$$A F = F C$$

Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to A C at its middle point F.

PROBLEM 2. To Construct an Angle Equal to a Given Angle.

Draw the line O C about 2 inches long and the line O A of about the same length. The angle formed by these lines may be any convenient size (about 45 degrees is suitable). This angle A O C is the given angle.

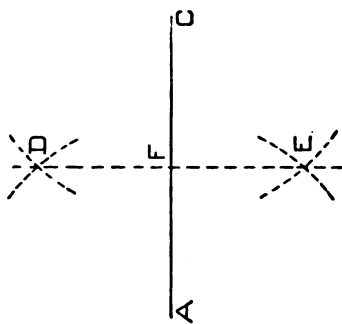
Now draw F G a horizontal line about $2\frac{1}{4}$ inches long and let F the left-hand extremity be the vertex of the angle to be constructed.

With O as a center and any convenient radius (about $1\frac{1}{2}$ inches) describe the arc L M cutting both O A and O C. With F as a center and the same radius draw the indefinite arc O Q. Now set the compass so that the distance between the pencil and the needle point is equal to the chord L M. With Q as a center and a radius equal to L M draw an arc cutting the arc O Q at P. Through F and P draw the straight line F E. The angle E F G is the required angle since it is equal to A O C.

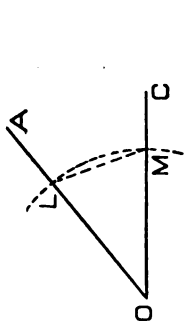
Proof. Since the chords of the arcs L M and P Q are equal the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

PROBLEM 3. To Draw Through a Given Point a Line Parallel to a Given Line.

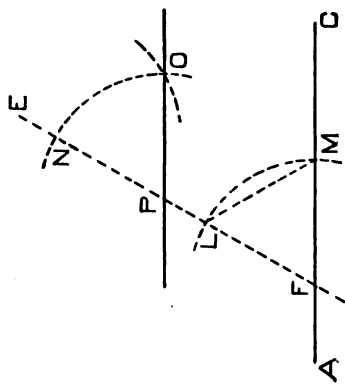
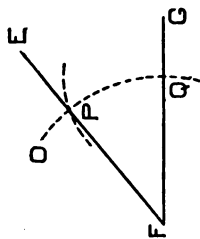
First Method. Draw the horizontal straight line A C about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. Through the point P draw an oblique line F E forming any convenient angle with A C. (Make the angle about 60 degrees). Now construct an angle equal to P F C having the vertex at P and one side the line E P. (See problem 2). This may be done as follows: With F as a center and any convenient radius, describe the arc L M. With the same radius draw the indefinite arc N O using P as the center. With N as a center and a radius equal to the chord L M, draw an arc cutting the arc N O at O. Through the points P and O draw a straight line which will be parallel to A C.



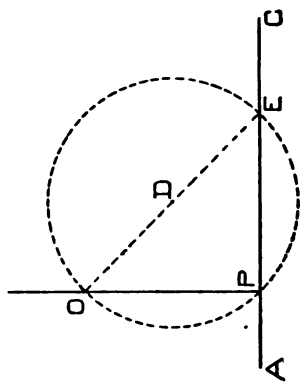
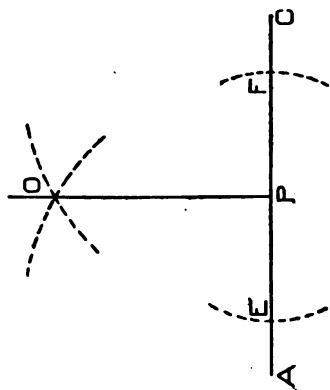
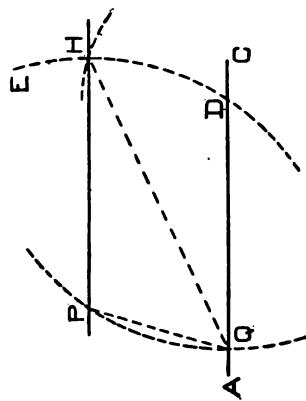
Problem 1



Problem 2



Problem 3



Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

PROBLEM 4. To Draw Through a Given Point a Line Parallel to a Given Line.

Second Method. Draw the straight line A C about $3\frac{1}{4}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. With P as a center and any convenient radius (about $2\frac{1}{2}$ inches) draw the indefinite arc E D cutting the line A C. Now with the same radius and with D as a center, draw an arc P Q. Set the compass so that the distance between the needle point and the pencil is equal to the chord P Q. With D as a center and a radius equal to P Q, describe an arc cutting the arc E D at H. A line drawn through P and H will be parallel to A C.

Proof. Draw the line Q H. Since the arcs P Q and H D are equal and have the same radii, the angles P H Q and H Q D are equal. Two lines are parallel if the alternate interior angles are equal.

PROBLEM 5. To Draw a Perpendicular to a Line from a Point in the Line.

First Method. When the point is near the middle of the line.

Draw the horizontal line A C about $3\frac{1}{2}$ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius (about $1\frac{1}{4}$ inches) draw two arcs cutting the line A C at E and F. Now with E and F as centers and any convenient radius (about $2\frac{1}{2}$ inches) describe arcs intersecting at O. The line O P will be perpendicular to A C at P.

Proof. The points P and O are equally distant from E and F. Hence a line drawn through them is perpendicular to the middle point of E F which is P.

PROBLEM 6. To Draw a Perpendicular to a Line from a Point in the Line.

Second Method. When the point is near the end of the line.

Draw the line A C about $3\frac{1}{2}$ inches long. Assume the given point P to be about $\frac{3}{4}$ inch from the end A. With any point D as a center and a radius equal to D P, describe an arc cutting A C at E. Through E and D draw the diameter E O. A line from O to P is perpendicular to A C at P.

Proof. The angle O P E is inscribed in a semi-circle ; hence it is a right angle, and the sides O P and P E are perpendicular to each other.

After completing these figures draw pencil lines for the lettering. The words "*PLATE IV*" and the date and name should be placed in the border, as in preceding plates. To letter the words "Problem 1," "Problem 2," etc., draw horizontal lines $\frac{1}{4}$ inch above the horizontal center line and the lower border line. Draw another line $\frac{3}{16}$ inch above, to limit the height of the P, b and l. Draw a third line $\frac{1}{8}$ inch above the lower line as a guide line for the tops of the small letters.

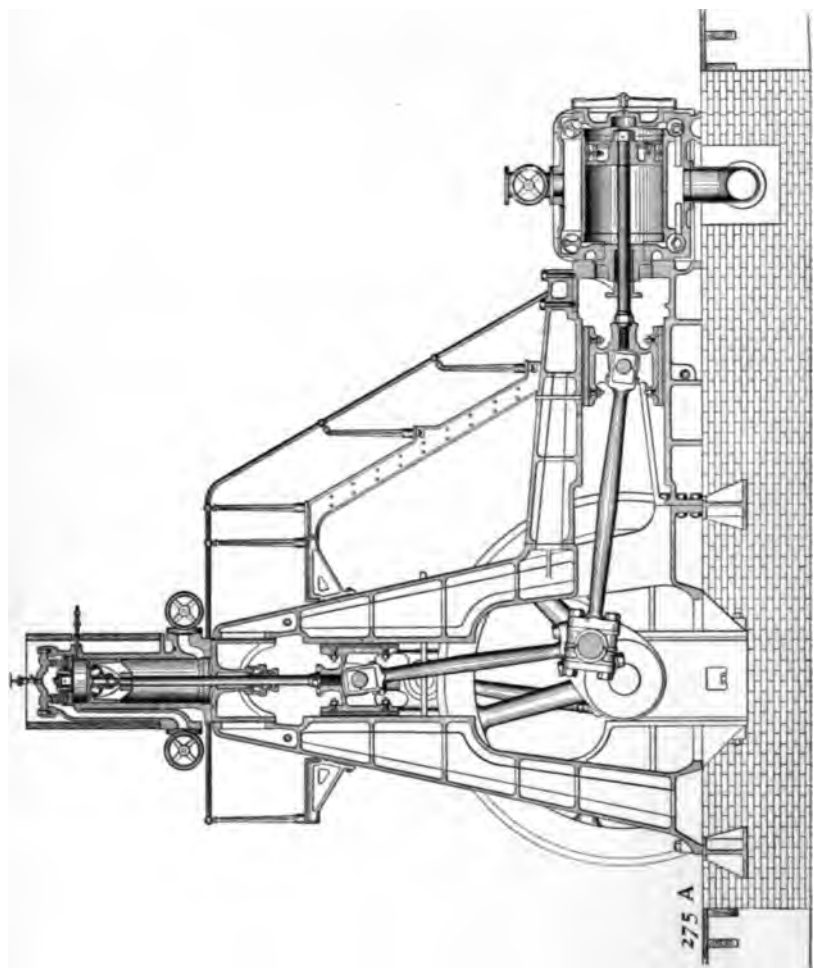
Inking. In inking *PLATE IV* the figures should be inked first. The line A C of Problem 1 should be a full line as it is the given line ; the arcs and line D E, being construction lines should be dotted. In Problem 2, the sides of the angles should be full lines. Make the chord L M and the arcs dotted, since as before, they are construction lines.

In Problem 3, the line A C is the given line and P O is the line drawn parallel to it. As E F and the arcs do not form a part of the problem but are merely construction lines, drawn as an aid in locating P O, they should be dotted. In Problems 4, 5 and 6, the assumed lines and those found by means of the construction lines should be full lines. The arcs and construction lines should be dotted. In Problem 6, the entire circumference need not be inked, only that part is necessary that is used in the problem. The inked arc should however be of sufficient length to pass through the points O, P and E.

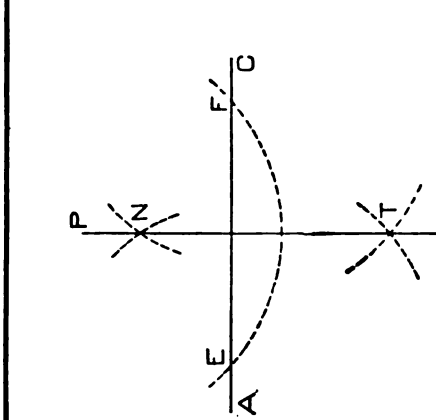
After inking the figures, the border lines should be inked with a heavy line as before. Also, the words "*PLATE IV*" and the date and the student's name. Under each problem the words "Problem 1," "Problem 2," etc., should be inked ; lower case letters being used as shown.

PLATE V.

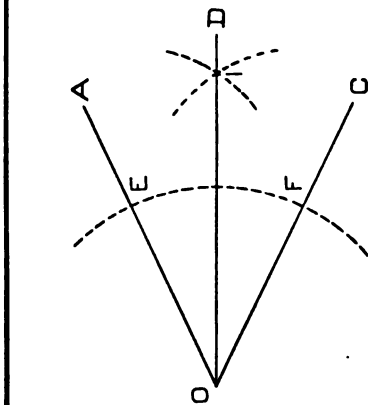
Pencilling. In laying out the border lines and centre lines follow the directions given for *PLATE IV*. The dot and dash lines should be drawn in the same manner as there are to be six problems on this plate.



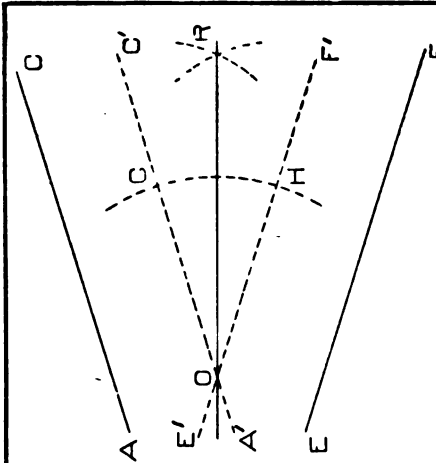
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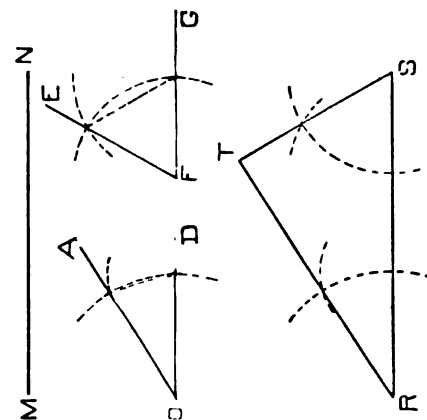
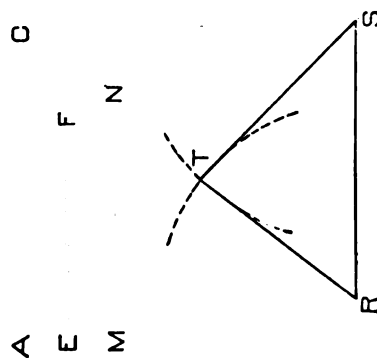
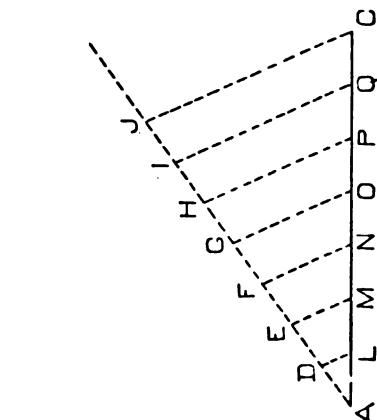
Problem 7



Problem 8



Problem 9



PROBLEM 7. To Draw a Perpendicular to a Line from a Point without the Line.

Draw the horizontal straight line AC about $3\frac{1}{4}$ inches long. Assume the point P about $1\frac{1}{2}$ inches above the line. With P as a center and any convenient radius (about 2 inches) describe an arc cutting AC at E and F . The radius of this arc must always be such that it will cut AC in two points; the nearer the points E and F are to A and C , the greater will be the accuracy of the work. Now with E and F as centers and any convenient radius (about $2\frac{1}{4}$ inches) draw the arcs intersecting below AC at T . A line through the points P and T will be perpendicular to AC .

In case there is not room below AC to draw the arcs, they may be drawn intersecting above the line as shown at N . Whenever convenient, draw the arcs below AC for greater accuracy.

Proof. Since P and T are equally distant from E and F , the line PT is perpendicular to AC .

PROBLEM 8. To Bisect a Given Angle.

First Method. When the sides intersect.

Draw the lines OC and OA forming any angle (from 45 to 60 degrees). These lines should be about 3 inches long. With O as a center and any convenient radius (about 2 inches) draw an arc intersecting the sides of the angle at E and F . With E and F as centers and a radius of $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, describe short arcs intersecting at I . A line OD , drawn through the points O and I , bisects the angle.

In solving this problem the arc EF should not be too near the vertex if accuracy is desired.

Proof. The central angles AOD and DOC are equal because the arc EF is bisected by the line OD . The point I is equally distant from E and F .

PROBLEM 9. To Bisect a Given Angle.

Second Method. When the lines do not intersect.

Draw the lines AC and EF about 4 inches long and in the positions as shown on *PLATE I*. Draw $A'C'$ and $E'F'$ parallel to AC and EF and at such equal distances from them that they will intersect at O . Now bisect the angle $C'OF'$ by

the method of Problem 8. Draw the arc GH and with G and H as centers draw the arcs intersecting at R . The line OR bisects the angle.

Proof. Since $A'C'$ is parallel to AC and $E'F'$ parallel to EF , the angle $C'OF'$ is equal to the angle formed by the lines AC and EF . Hence as OR bisects angle $C'OF'$ it also bisects the angle formed by the lines AC and EF .

PROBLEM 10. To Divide a Given Line into any Number of Equal Parts.

Let AC , about $3\frac{3}{4}$ inches long, be the given line. Let us divide it into 7 equal parts. Draw the line AJ at least 4 inches long, forming any convenient angle with AC . On AJ lay off, by means of the dividers or scale, points D, E, F, G , etc., each $\frac{1}{2}$ inch apart. If dividers are used the spaces need not be exactly $\frac{1}{2}$ inch. Draw the line JG and through the points D, E, F, G , etc., draw lines parallel to JG . These parallels will divide the line AC into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

PROBLEM 11. To Construct a Triangle having given the Three Sides.

Draw the three sides as follows:

AC , $2\frac{3}{4}$ inches long.

EF , $1\frac{1}{8}$ inches long.

MN , $2\frac{3}{8}$ inches long.

Draw RS equal in length to AC . With R as a center and a radius equal to EF describe an arc. With S as a center and a radius equal to MN draw an arc cutting the arc previously drawn, at T . Connect T with R and S to form the triangle.

PROBLEM 12. To Construct a Triangle having given One Side and the Two Adjacent Angles.

Draw the line MN $3\frac{1}{4}$ inches long and draw two angles AOD and $EF G$. Make the angle AOD about 30 degrees and $EF G$ about 60 degrees.

Draw RS equal in length to MN and at R construct an

angle equal to $\angle AOD$. At S construct an angle equal to $\angle EFG$ by the method used in Problem 2. *PLATE V* shows the necessary arcs. Produce the sides of the angles thus constructed until they meet at T . The triangle RTS will be the required triangle.

After drawing these six figures in pencil, draw the pencil lines for the lettering. The lines for the words "*PLATE V*," date and name, should be pencilled as explained on page 20. The words "Problem 7," "Problem 8," etc., are lettered as for *PLATE IV*.

Inking. In inking *PLATE V*, the same principles should be followed as stated with *PLATE IV*. The student should apply these principles and not make certain lines dotted just because they are shown dotted in *PLATE V*.

After inking the figures, the border lines should be inked and the lettering inked as already explained in connection with previous plates.

PLATE VI.

Pencilling. Lay out this plate in the same manner as the two preceding plates.

PROBLEM 13. To describe an Arc or Circumference through Three Given Points not in the same straight line.

Locate the three points A , B and C . Let the distance between A and B be about 2 inches and the distance between A and C be about $2\frac{1}{4}$ inches. Connect A and B and A and C . Erect perpendiculars to the middle points of AB and AC . This may be done as explained with Problem 1. With A and B as centers and a radius of about $1\frac{1}{2}$ inches, describe the arcs intersecting at I and J . With A and C as centers and with a radius of about $1\frac{3}{4}$ inches draw the arcs, intersecting at E and F . Now draw light pencil lines connecting the intersections I and J and E and F . These lines will intersect at O .

With O as a center and a radius equal to the distance OA , describe the circumference passing through A , B and C .

Proof. The point O is equally distant from A , B and C , since it lies in the perpendiculars to the middle points of AB and

A C. Hence the circumference will pass through A, B and C.

PROBLEM 14. To inscribe a Circle in a given Triangle.

Draw the triangle L M N of any convenient size. M N may be made $3\frac{1}{4}$ inches, L M, $2\frac{3}{4}$ inches, and L N, $3\frac{1}{2}$ inches. Bisect the angles M L N and L M N. The bisectors M I and L J may be drawn by the method used in Problem 8. Describe the arcs A C and E F, having centers at L and M respectively. The arcs intersecting at I and J are drawn as already explained. The bisectors of the angles intersect at O, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from O to one of the sides.

Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

PROBLEM 15. To inscribe a Regular Pentagon in a given Circle.

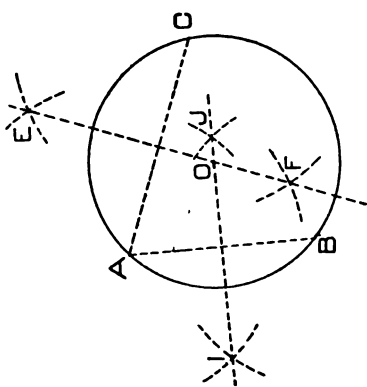
With O as a center and a radius of about $1\frac{1}{2}$ inches, describe the given circle. With the T square and triangles draw the center lines A C and E F. These lines should be perpendicular to each other and pass through O. Bisect one of the radii, such as O C, and with this point H as a center and a radius H E, describe the arc E P. This arc cuts the diameter A C at P. With E as a center and a radius E P, draw arcs cutting the circumference at L and Q. With the same radius and a center at L, draw the arc, cutting the circumference at M. To find the point N, use either M or Q as a center and the distance E P as a radius.

The pentagon is completed by drawing the chords E L, L M, M N, N Q and Q E.

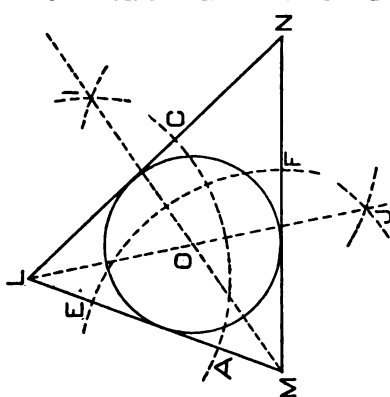
PROBLEM 16. To inscribe a Regular Hexagon in a given Circle.

With O as a center and a radius of $1\frac{3}{8}$ inches draw the given circle. With the T square draw the diameter A D. With D as a center, and a radius equal to O D, describe arcs cutting the circumference at C and E. Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F. Draw the hexagon by joining the points thus formed.

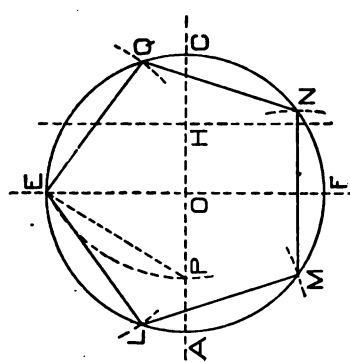
To inscribe a regular hexagon in a circle mark off chords equal in length to the radius.



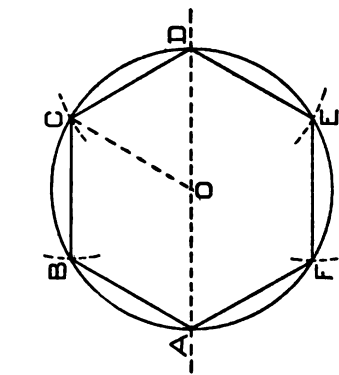
Problem 13



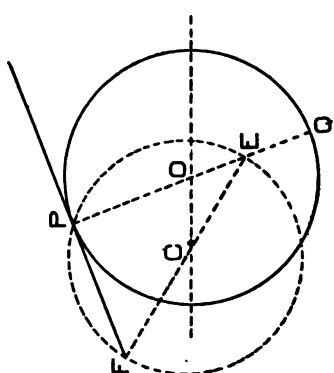
Problem 14



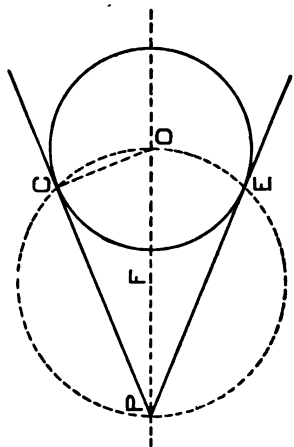
Problem 15



Problem 16



Problem 17



Problem 18

To inscribe an equilateral triangle in a circle the same method may be used. The triangle is formed by joining the opposite vertices of the hexagon.

Proof. The triangle OCD is an equilateral triangle by construction. Then the angle COD is one-third of two right angles and one-sixth of four right angles. Hence arc CD is one-sixth of the circumference and the chord is a side of a regular hexagon.

PROBLEM 17. To draw a line Tangent to a Circle at a given point on the circumference.

With O as a center and a radius of about $1\frac{1}{4}$ inches draw the given circle. Assume some point P on the circumference. Join the point P with the center O and through P draw a line FP perpendicular to PO . This may be done in any one of several methods. Since P is the extremity of OP the method given in Problem 6 of *PLATE IV*, may be used.

Produce PO to Q . With any center C , and a radius CP draw an arc or circumference passing through P . Draw EF a diameter of the circle whose center is C and through F and P draw the tangent.

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

PROBLEM 18. To draw a line Tangent to a Circle from a point outside the circle.

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about $2\frac{1}{2}$ inches from the center of the circle. Draw a straight line passing through P and O . Bisect PO and with the middle point F as a center describe the circle passing through P and O . Draw a line through P and the intersection of the two circumferences C . The line PC is tangent to the given circle. Similarly PE is tangent to the circle.

Proof. The angle PCO is inscribed in a semi-circle and hence is a right angle. Since PCO is a right angle PC is perpendicular to CO . The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *PLATE VI* the same method should be

followed as in previous plates. The name and address should be lettered in inclined Gothic capitals as before.

PLATE VII.

Pencilling. *PLATE VII* should be laid out in the same manner as previous plates. Six problems on the ellipse, spiral, parabola and hyperbola are to be constructed in the six spaces.

PROBLEM 19. To draw an Ellipse when the Axes are given.

Draw the lines $L M$ and $C D$ about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively. Let $C D$ be perpendicular to $M N$ at its middle point P . Make $C P = P D$. These two lines are the axes. With C as a center and a radius equal to one-half the major axis or equal to $L P$, draw the arc, cutting the major axis at E and F . These two points are the foci. Now mark off any convenient distances on $P M$, such as A , B and G .

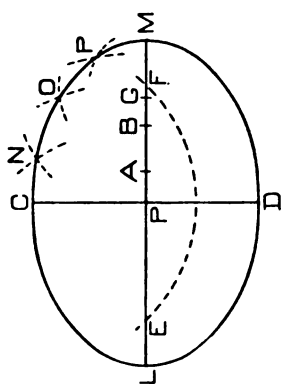
With E as a center and a radius equal to $L A$, draw arcs above and below $L M$. With F as a center, and a radius equal to $A M$ describe short arcs cutting those already drawn as shown at N . With E as a center and a radius equal to $L B$ draw arcs above and below $L M$ as before. With F as a center and a radius equal to $B M$, draw arcs intersecting those already drawn as shown at O . The point P and others are found by repeating the process. The student is advised to find at least 12 points on the curve — 6 above and 6 below $L M$. These 12 points with L , C , M and D will enable the student to draw the curve.

After locating these points, a free hand curve passing through them should be sketched.

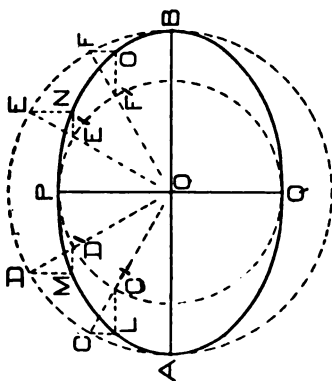
PROBLEM 20. To draw an Ellipse when the two Axes are given.

Second Method. Draw the two axes $A B$ and $P Q$ in the same manner as for Problem 19. With O as a center and a radius equal to one-half the major axis, describe the circumference $A C D E F B$. Similarly with the same center and a radius equal to one-half the minor axis, describe a circle. Draw any radii such as $O C$, $O D$, $O E$, $O F$, etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. At the

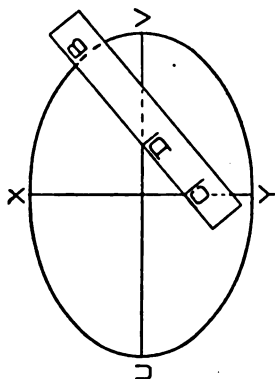




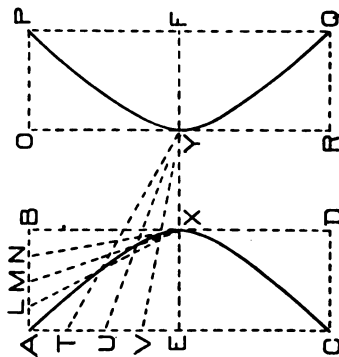
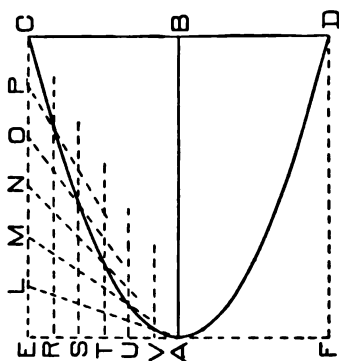
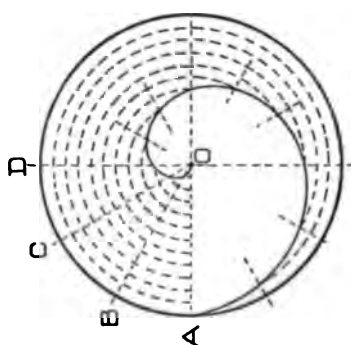
Problem 19



Problem 20



Problem 21



points of intersection of the radii with the large circle C D E and F, draw *vertical* lines and from the intersection of the radii with the small circle C', D', E', and F', draw *horizontal* lines intersecting the vertical lines. The intersections of these lines are points on the curve.

As in Problem 19, a free hand curve should be sketched passing through these points. About five points in each quadrant will be sufficient.

PROBLEM 21. To draw an Ellipse by means of a Trammel.

As in the two preceding problems, draw the major and minor axes, U V and X Y. Take a slip of paper having a straight edge and mark off C B equal to one-half the major axis, and D B one-half the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done the point B will mark various points on the curve. Find as many points as necessary and sketch the curve.

PROBLEM 22. To draw a Spiral of one turn in a circle.

Draw a circle with the center at O and a radius of $1\frac{1}{2}$ inches. Mark off on the radius O A, distances of one-eighth inch. As O A is $1\frac{1}{2}$ inches long there will be 12 of these distances. Draw circles through these points. Now draw radii O B, O C, O D, etc. each 30 degrees apart (use the 30 degree triangle). This will divide the circle into 12 equal parts. The curve starts at the center O. The next point is the intersection of the line O B and the first circle. The third point is the intersection of O C and the second circle. The fourth point is the intersection of O D and the third circle. Other points are found in the same way. Sketch in pencil the curve passing through these points.

PROBLEM 23. To draw a Parabola when the Abscissa and Ordinate are given.

Draw the straight line A B about three inches long. This line is the axis or as it is sometimes called the abscissa. At A and B draw lines perpendicular to A B. Also with the T square draw E C and F D, $1\frac{1}{2}$ inches above and below A B. Let A be

the vertex of the parabola. Divide A E into any number of equal parts and divide E C into the same number of equal parts. Through the points of division, R, S, T, U and V, draw horizontal lines and connect L, M, N, O and P, with A. The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of A L and the line V is one point and the intersection of A M and the line U is another.

The lower part of the curve A D is drawn in the same manner.

PROBLEM 24. To draw a Hyperbola when the abscissa E X, the ordinate A E and the diameter X Y are given.

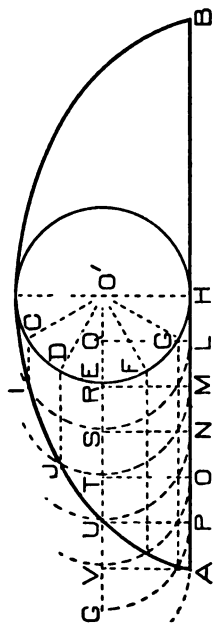
Draw E F about 3 inches long and mark the point X, 1 inch from E and the point Y, 1 inch from X. With the triangle and T square, draw the rectangles A B D C and O P Q R such that A B is 1 inch in length and A C, 3 inches in length. Divide A E into any number of equal parts and A B into the same number of equal parts. Draw L X, M X and N X; also connect T, U and V with Y. The first point on the curve is the intersection A; the next is the intersection of T Y and L X; the third the intersection of U Y and M X. The remaining points are found in the same manner. The curve X C and the right-hand curve P Y Q are found by repeating the process.

Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. The construction lines should be dotted. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23 and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position as shown, or it may be drawn outside of the ellipse in any convenient place.

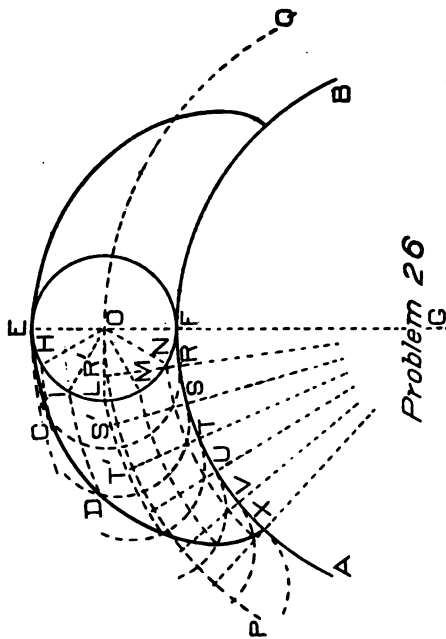
The same lettering should be done on this plate as on previous plates.

PLATE VIII.

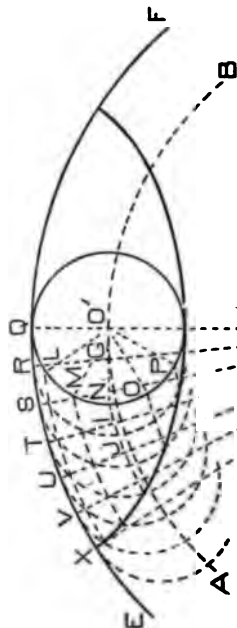
Pencilling. In laying out Plate VIII, draw the border lines and horizontal and vertical center lines as in previous plates, to divide the plate into four spaces for the four problems.



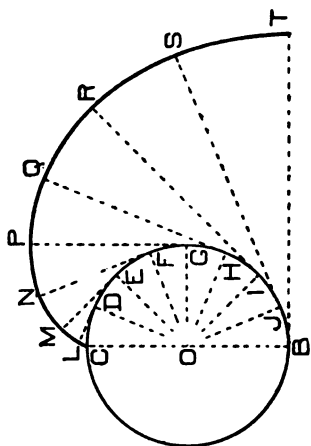
Problem 25



Problem 26



Problem 27



Problem 28

PROBLEM 25. To construct a Cycloid when the diameter of the generating circle is given.

With O' as a center and a radius of $\frac{7}{8}$ inch draw a circle, and tangent to it draw the indefinite horizontal straight line $A B$. Divide the circle into any number of equal parts (12 for instance) and through these points of division C, D, E, F , etc., draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc $C D$, mark off the points L, M, N, O, P on the line $A B$, commencing at the point H . At these points erect perpendiculars to the center line $G O'$. This center line is drawn through the point O' with the T square and is the line of centers of the generating circle as it rolls along the line $A B$. Now with the intersections Q, R, S, T , etc., of these verticals with the center line as centers describe arcs of circles as shown. The points on the curve are the intersections of these arcs and the horizontal lines drawn through the points C, D, E, F , etc. Thus the intersection of the arc whose center is Q and the horizontal line through C is a point I on the curve. Similarly, the intersection of the arc whose center is R and the horizontal line through D is another point J on the curve. The remaining points, as well as those on the right-hand side, are found in the same manner. To obtain great accuracy in this curve, the circle should be divided into a large number of equal parts, because the greater the number of divisions the less the error due to the difference in length of a chord and its arc.

PROBLEM 26. To construct an Epicycloid when the diameter of the generating circle and the diameter of the director circle are given.

The epicycloid and hypocycloid may be drawn in the same manner as the cycloid if arcs of circles are used in place of the horizontal lines. With O as a center and a radius of $\frac{3}{4}$ inch describe a circle. Draw the diameter $E F$ of this circle and produce $E F$ to G such that the line $F G$ is $2\frac{3}{4}$ inches long. With G as a center and a radius of $2\frac{3}{4}$ inches describe the arc $A B$ of the director circle. With the same center G , draw the arc $P Q$ which will be the path of the center of the generating circle as it rolls along the arc $A B$. Now divide the generating circle into

any number of equal parts (twelve for instance) and through the points of division H, I, L, M, and N, draw arcs having G as a center. With the dividers set so that the distance between the points is equal to the chord H I, mark off distances on the director circle A F B. Through these points of division R, S, T, U, etc., draw radii intersecting the arc P Q in the points R', S', T', etc., and with these points as centers describe arcs of circles as in Problem 25. The intersections of these arcs with the arcs already drawn through the points H, I, L, M, etc., are points on the curve. Thus the intersection of the circle whose center is R' with the arc drawn through the point H is a point upon the curve. Also the arc whose center is S' with the arc drawn through the point I is another point on the curve. The remaining points are found by repeating this process.

PROBLEM 27. To draw an Hypocycloid when the diameter of the generating circle and the radius of the director circle are given.

With O as a center and a radius of 4 inches describe the arc E F, which is the arc of the director circle. Now with the same center and a radius of $3\frac{1}{4}$ inches, describe the arc A B, which is the line of centers of the generating circle as it rolls on the director circle. With O' as a center and a radius of $\frac{3}{4}$ inch describe the generating circle. As before, divide the generating circle into any number of equal parts (12 for instance) and with these points of division L, M, N, O, etc., draw arcs having O as a center. Upon the arc E F, lay off distances Q R, R S, S T, etc., equal to the chord Q L. Draw radii from the points R, S, T, etc., to the center of the director circle O and describe arcs of circles having a radius equal to the radius of the generating circle, using the points G, I, J, etc., as centers. As in Problem 26, the intersections of the arcs are the points on the curve. By repeating this process, the right-hand portion of the curve may be drawn.

PROBLEM 28. To draw the Involute of a circle when the diameter of the base circle is known.

With point O as a center and a radius of 1 inch, describe the base circle. Now divide the circle into any number of equal parts 16 for instance) and connect the points of division with the cen-

ter of the circle by drawing the radii $O C$, $O D$, $O E$, $O F$, etc., to $O B$. At the point D , draw a light pencil line perpendicular to the radius $O D$. This line will be tangent to the circle. Similarly at the points E , F , G , H , etc., draw tangents to the circle. Now set the dividers so that the distance between the points will be equal to the chord of the arc $C D$, and measure this distance from D along the tangent. Beginning with the point E , measure on the tangent a distance equal to two of these chords, from the point F measure on the tangent three divisions, and from the point G measure a distance equal to four divisions on the tangent $G P$. Similarly, measure distances on the remaining tangents, each time adding the length of the chord. This will give the points Q , R , S and T . Now sketch a light pencil line through the points L , M , N , P , etc., to T . This curve will be the involute of the circle.

Inking. The same rules are to be observed in inking *PLATE VIII* as were followed in the previous plates, that is, the curves should be inked in a full line, using the French or irregular curve. All arcs and lines used in locating the points on one-half of the curve should be inked in dotted lines. The arcs and lines used in locating the points of the other half of the curve may be left in pencil in Problems 25 and 26. In Problem 28, all construction lines should be inked. After completing the problems the same lettering should be done on this plate as on previous plates.

MECHANICAL DRAWING.

PART III.

PROJECTIONS.

ORTHOGRAPHIC PROJECTION.

Orthographic Projection is the art of representing objects of three dimensions by views on two planes at right angles to each other, in such a way that the forms and positions may be completely determined. The two planes are called planes of projection or co-ordinate planes, one being vertical and the other horizontal, as shown in Fig. 1. These planes are sometimes designated V and H respectively. The intersection of V and H is known as the ground line G L.

The view or projection of the figure on the plane gives the same appearance to the eye placed in a certain position that the object itself does. This position of the eye is at an infinite distance from the plane so that the rays from it to points of a limited object are all perpendicular to the plane. Evidently then the view of a point of the object is on the plane and in the ray through the point and the eye or where this perpendicular to the plane pierces it.

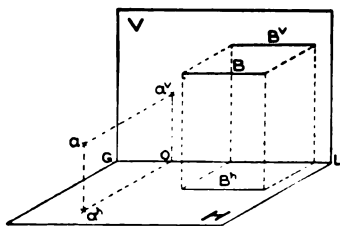


Fig. 1.

Let a , Fig. 1, be a point in space, draw a perpendicular from a to GL . Where this line strikes the vertical plane, the projection of a is found, namely at a^v . Then drop a perpendicular from a to the horizontal plane striking it at a^h , which is the horizontal projection of the point. Drop a perpendicular from a^v to H ; this will intersect GL at o and be parallel and equal to the line aa^h . In the same way draw a perpendicular from a^h to V , this also will intersect GL at o and will be parallel and equal to aa^v . In other words, the perpendicular to GL from the projection of a point on either plane equals the distance of the point from the other plane. B in Fig. 1, shows a line in space. B^v is its V projection, and B^h

its H projection, these being determined by finding views of points at its ends and connecting the points.

Instead of horizontal projection and vertical projection, the terms **plan** and **elevation** are commonly used.

Suppose a cube, one inch on a side, to be placed as in Fig. 2, with the top face horizontal and the front face parallel to the vertical plane. Then the plan will be a one-inch square, and the elevation also a one-inch square. In general the plan is a representation of the top of the object, and the elevation a view of the front. The plan then is a top view, and the elevation a front view.

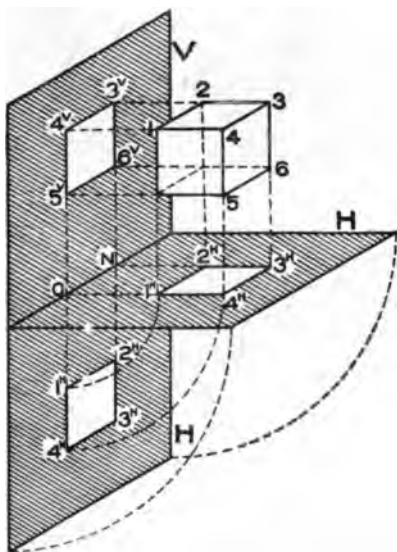


Fig. 2.

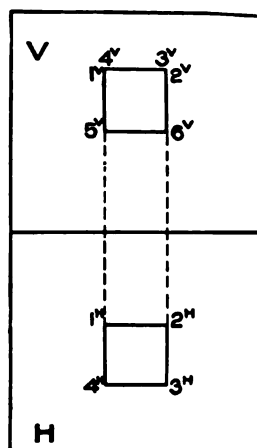


Fig. 3.

Thus far the two planes have been represented at right angles to each other, as they are in space. In order that they may be shown more simply and on the one plane of the paper, H is revolved about G L as an axis until it lies in the same plane as V as shown in Fig. 2. The lines $1^h O$ and $2^h N$, being perpendicular to G L, are in the same straight line as $5^v O$ and $6^v N$, which also are perpendicular to G L. That is—*two views of a point are always in a line perpendicular to G L*. From this it is evident that the plan must be vertically below the elevation, point for point. Now looking directly at the two planes in the revolved position, we

get a true orthographic projection of the cube as shown in Fig. 3.

All points on an object at the same height must appear in elevation at the same distance above the ground line. If numbers 1, 2, 3, and 4 on the plan, Fig. 3, indicate the top corners of the cube, then these four points, being at the same height, must be shown in elevation at the same height and at the top, $\frac{4v}{1v}$ and $\frac{3v}{2v}$.

The top of the cube, 1, 2, 3, 4, is shown in elevation as the straight line $\frac{4v}{1v} \frac{3v}{2v}$. This illustrates the fact that *if a surface is perpendicular to either plane or projection, its projection on that plane is simply a line; a straight line if the surface is plane, a curved line if the surface is curved.* From the same figure it is seen that the top edge of the cube, 1 4, has for its projection on the vertical plane the point $\frac{4v}{1v}$, the principle of which is stated in this way: *If a*

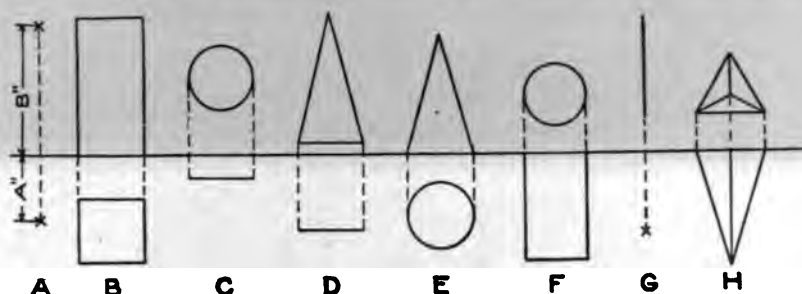


Fig. 4.

straight line is perpendicular to either V or H, its projection on that plane is a point, and on the other plane is a line equal in length to the line itself, and perpendicular to the ground line.

Fig. 4 is given as an exercise to help to show clearly the idea of plan and elevation.

- A = a point B' above H, and A' in front of V.
- B = square prism resting on H, two of its faces parallel to V.
- C = circular disc in space parallel to V.
- D = triangular card in space parallel to V.
- E = cone resting on its base on H.
- F = cylinder perpendicular to V, and with one end resting against V.
- G = line perpendicular to H.
- H = triangular pyramid above H, with its base resting against V.

Suppose in Fig. 5, that it is desired to construct the projections of a prism $1\frac{1}{2}$ in. square, and 2 in. long, standing on one end on the horizontal plane, two of its faces being parallel to the vertical plane. In the first place, as the top end of the prism is a square, the top view or plan will be a square of the same size, that is, $1\frac{1}{2}$ in. Then since the prism is placed parallel to and in front of the vertical plane the plan, $1\frac{1}{2}$ in. square, will have two edges parallel to the ground line. As the front face of the prism

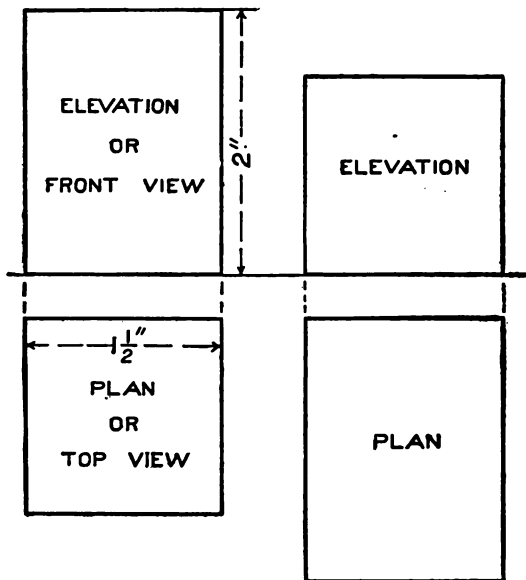


Fig. 5.

is parallel to the vertical plane its projection on V will be a rectangle, equal in length and width to the length and width respectively of the prism, and as the prism stands with its base on H, the elevation, showing height above H, must have its base on the ground line. Observe carefully that points in elevation are vertically over corresponding points in plan.

The second drawing in Fig. 5 represents a prism of the same size lying on one side on the horizontal plane, and with the ends parallel to V.

The principles which have been used thus far may be stated as follows, —

1. If a line or point is on either plane, its other projection must be in the ground line.

2. Height above H is shown in elevation as height above the ground line, and distance in front of the vertical plane is shown in plan as distance from the ground line.

3. If a line is parallel to either plane, its actual length is shown on that plane, and its other projection is parallel to the ground line. A line oblique to either plane has its projection on that plane shorter than the line itself, and its other projection oblique to the ground line. No projection can be longer than the line itself.

4. A plane surface if parallel to either plane, is shown on

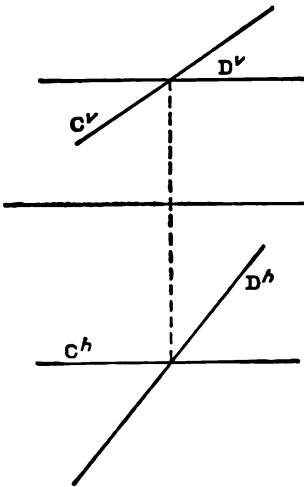


Fig. 6.

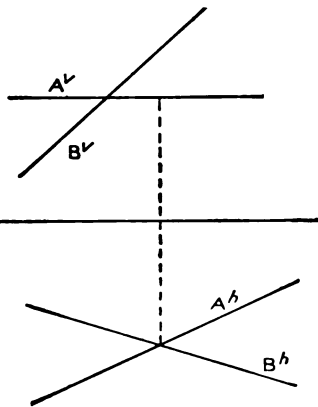


Fig. 7.

that plane in its true size and shape; if oblique it is shown smaller than the true size, and if perpendicular it is shown as a straight line. Lines parallel in space must have their V projections parallel to each other and also their H projections.

If two lines intersect, their projections must cross, since the point of intersection of the lines is a point on both lines, and therefore the projections of this point must be on the projections of both lines, or at their intersection. In order that intersecting lines may be represented, the vertical projections must intersect in a point vertically above the intersection of the horizontal pro-

jections. Thus Fig. 6 represents two lines which do intersect as C^v crosses D^v at a point vertically above the intersection of C^h and D^h . In Fig. 7, however, the lines do not intersect since the intersections of their projections do not lie in the same vertical line.

In Fig. 8 is given the plan and elevation of a square pyramid standing on the horizontal plane. The height of the pyramid is the distance $A B$. The slanting edges of the pyramid, $A C$, $A D$, etc., must be all of the same length, since A is directly above the center of the base.

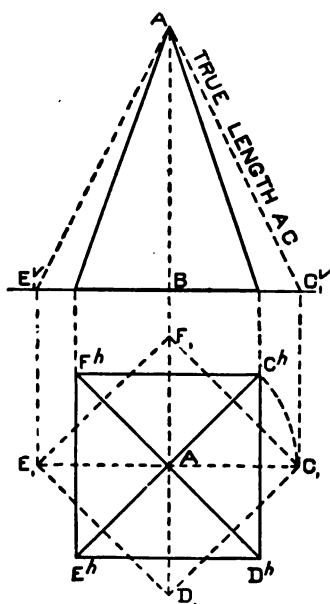


Fig. 8.

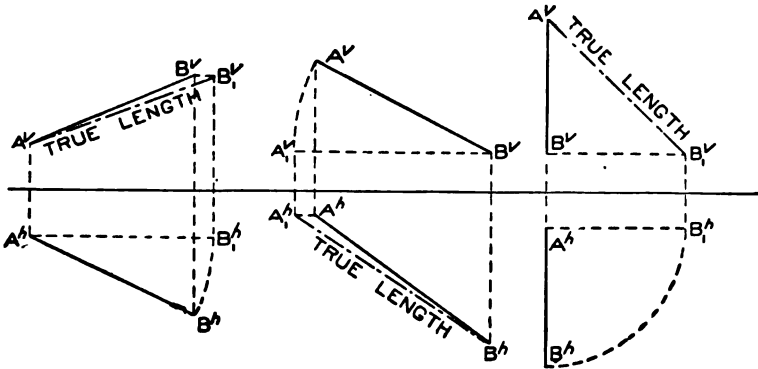
What this length is, however, does not appear in either projection, as these edges are not parallel to either V or H .

Suppose that the pyramid be turned around into the dotted position $C_1 D_1 E_1 F_1$, where the horizontal projections of two of the slanting edges, $A C_1$ and $A E_1$, are parallel to the ground line. These two edges, having their horizontal projections parallel to the ground line, are now parallel to V , and therefore their new vertical projections will show their true lengths. The base of the pyramid is still on H , and therefore is projected on V in the ground line. The apex is in the same place as before, hence the vertical projection of

the pyramid in its new position is shown by the dotted lines. The vertical projection $A C_1^v$ is the true length of edge $A C$. Now if we wish to find simply the true length of $A C$, it is unnecessary to turn the whole pyramid around, as the one line $A C$ will be sufficient.

The principle of finding the true length of lines is this, and can be applied to any case: Swing one projection of the line parallel to the ground line, using one end as center. On the other projection the moving end remains at the same distance from the ground line, and of course vertically above or below the same end in its parallel position. This new projection of the line shows its true length. See the three Figures at the top of page 9.

Third plane of projection or profile plane. A plane perpendicular to both co-ordinate planes, and hence to the ground line, is



called a *profile plane*. This plane is vertical in position, and may be used as a plane of projection. A projection on the profile plane is called a *profile view*, or *end view*, or sometimes *edge view*, and is often required in machine or other drawing when the plan and elevation do not sufficiently give the shape and dimensions.

A projection on this plane is found in the same way as on the

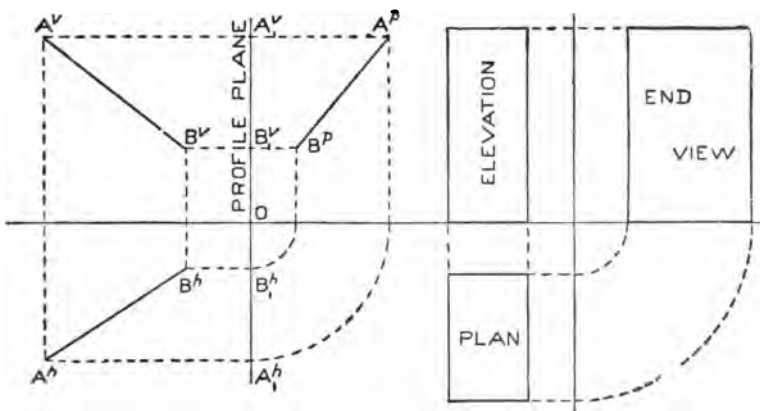


Fig. 9.

V plane, that is, by perpendiculars drawn from points on the object.

Since, however, the profile plane is perpendicular to the ground line, it will be seen from the front and top simply as a

straight line; in order that the size and shape of the profile view may be shown, the profile plane is revolved into V using its intersection with the vertical plane as the axis.

Given in Fig. 9, the line $A B$ by its two projections $A^v B^v$ and $A^h B^h$, and given also the profile plane. Now by projecting the line on the profile by perpendiculars, the points $A_1^v B_1^v$ and $B_1^h A_1^h$ are found. Revolving the profile plane like a door on its hinges, all points in the plane will move in horizontal circles, so the horizontal projections A_1^h and B_1^h will move in arcs of circles with O as center to the ground line, and the vertical projections B_1^v and A_1^v will move in lines parallel to the ground line to positions directly above the revolved points in the ground line, giving the profile view of the line $A^p B^p$. Heights, it will be seen, are the same in profile view

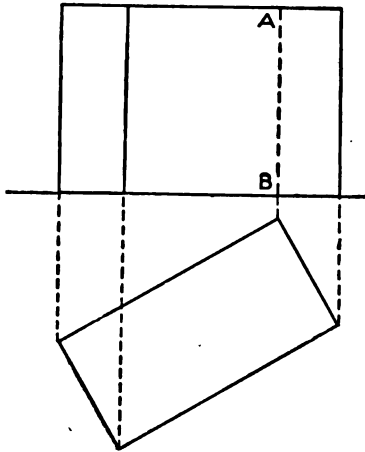


Fig. 10.

as in elevation. By referring to the rectangular prism in the same figure, we see that the elevation gives vertical dimensions and those parallel to V , while the end view shows vertical dimensions and those perpendicular to V . The profile view of any object may be found as shown for the line $A B$ by taking one point at a time.

In Fig. 10 there is represented a rectangular prism or block, whose length is twice the width. The elevation shows its height. As the prism is placed at

an angle, three of the vertical edges will be visible, the fourth one being invisible.

In mechanical drawing lines or edges which are invisible are drawn *dotted*. The edges which in projection form a part of the outline or contour of the figure must always be visible, hence always *full lines*. The plan shows what lines are visible in elevation, and the elevation determines what are visible in plan. In Fig. 10, the plan shows that the dotted edge $A B$ is the back edge, and in Fig. 11, the dotted edge $C D$ is found, by looking at the elevation, to be the lower edge of the triangular prism. In general,

if in elevation an edge projected *within* the figure is a back edge, it must be dotted, and in plan if an edge projected within the outline is a lower edge it is dotted.

Fig. 12 is a circular cylinder with the length vertical and

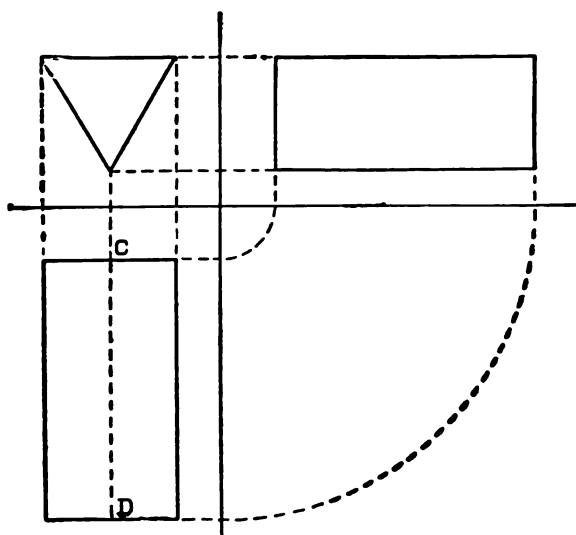


Fig. 11.

with a hole part way through as shown in elevation. Fig. 13 is plan, elevation and end view of a triangular prism with a square hole from end to end. The plan and elevation alone would be insufficient to determine positively the shape of the hole, but the end view shows at a glance that it is square.

In Fig. 14 is shown plan and elevation of the frustum of a square pyramid, placed with its base on the horizontal plane. If the frustum is turned through 30° , as shown in the plan of Fig. 15, the top view or plan must still be the same shape and size, and as the frustum has not been raised or lowered, the heights of all points must appear the same in elevation as before in Fig. 14. The elevation is easily found by projecting points up from the plan, and projecting the height of the top horizontally across from the first elevation, because the height does not change.

The same principle is further illustrated in Figs. 16 and 17. The elevation of Fig. 16 shows a square prism resting on one edge, and raised up at an angle of 30° on the right-hand side. The

plan gives the width or thickness, $\frac{1}{8}$ in. Notice that the length of the plan is greater than 2 in. and that varying the angle at

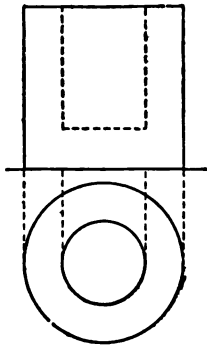


Fig. 12.

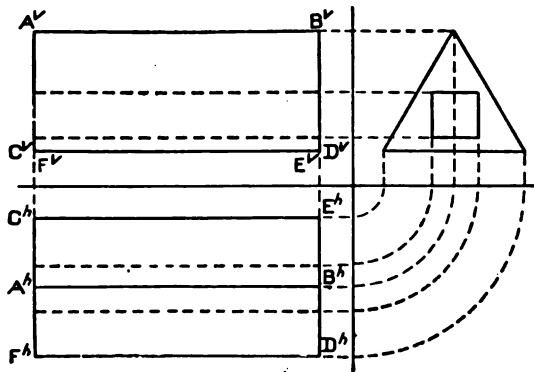


Fig. 13.

which the prism is slanted would change the length of the plan. Now if the prism be turned around through any angle with the vertical plane, the lower edge still being on H, and the inclination

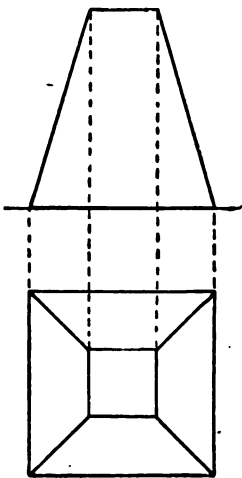


Fig. 14.

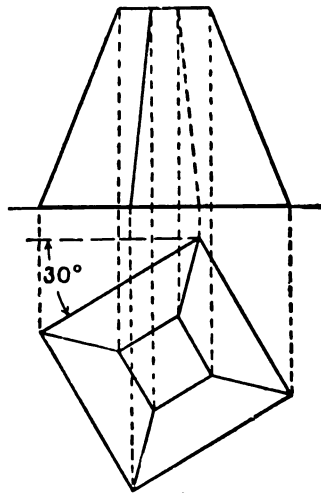


Fig. 15.

of 30° with H remaining the same, the plan must remain the same size and shape.

If the angle through which the prism be turned is 45° , we

have the second plan, exactly the same shape and size as the first. The elevation is found by projecting the corners of the prism ver-

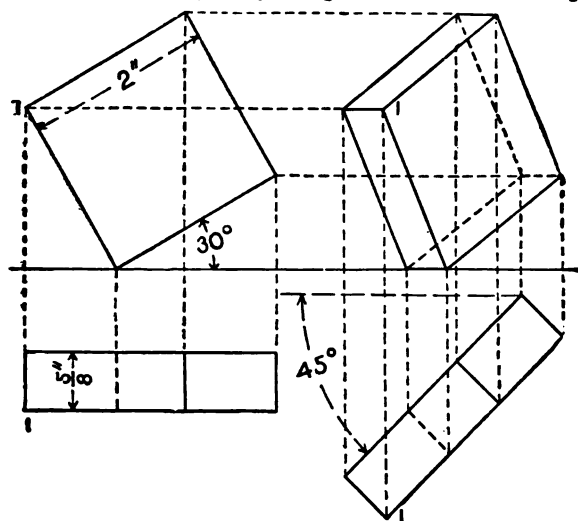


Fig. 16.

tically up to the heights of the same points in the first elevation. All the other points are found in the same way as point No. 1.

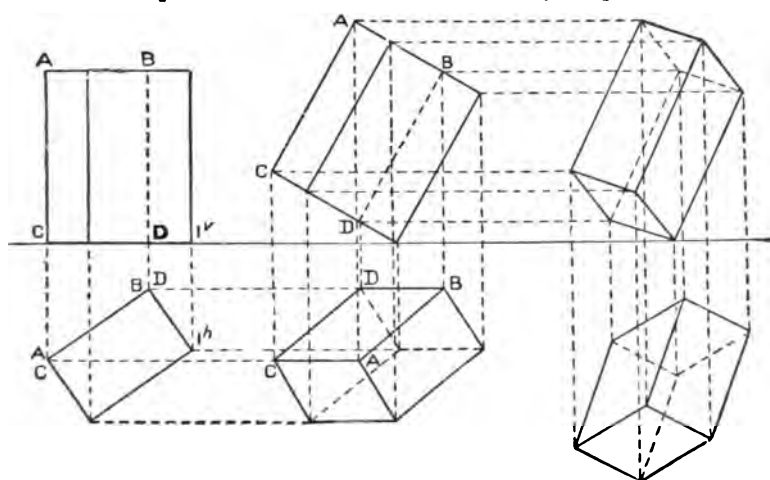


Fig. 17.

Three positions of a rectangular prism are shown in Fig. 17. In the first view, the prism stands on its base, its axis therefore

is parallel to the vertical plane. In the second position, the axis is still parallel to V and one corner of the base is on the horizontal plane. The prism has been turned as if on the line $1^A 1^S$ as an axis, so that the inclination of all the faces of the prism to the vertical plane remains the same as before. That is, if in the first figure the side A B C D makes an angle of 30° with the vertical, the same side in the second position still makes 30° with the vertical.

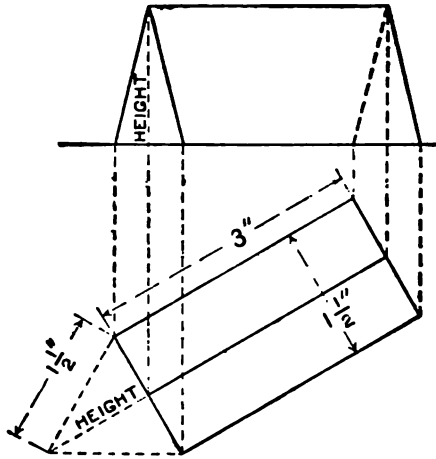


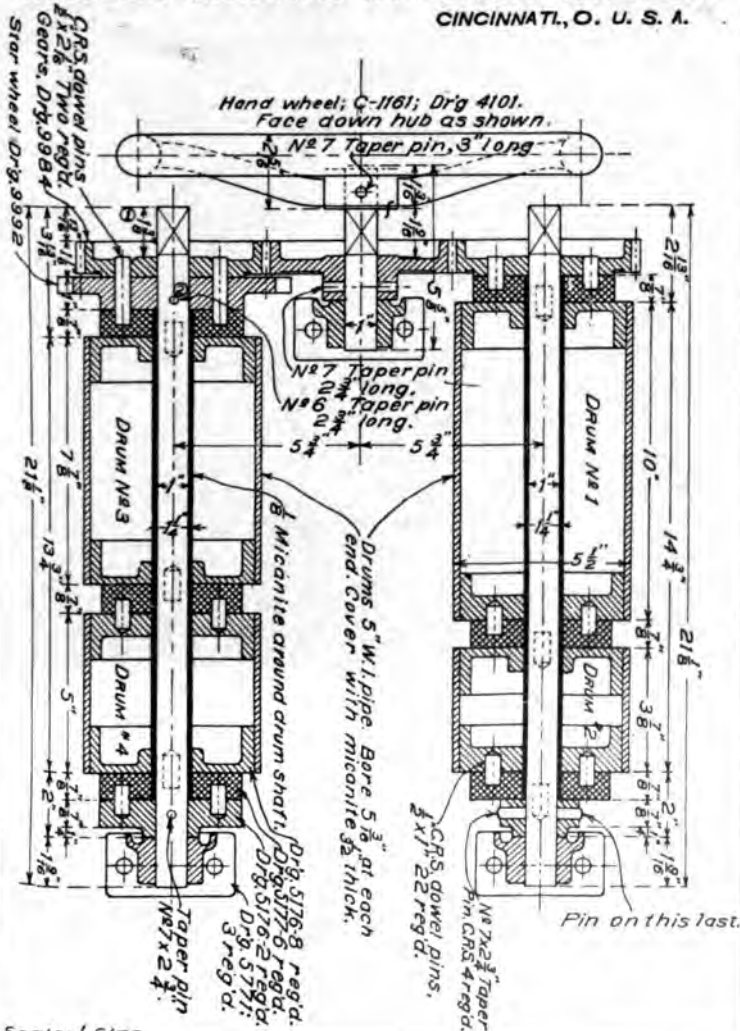
Fig. 18.

tical plane. Hence the elevation of No. 2 is the same shape and size as in the first case. The plan is found by projecting the corners down from the elevation to meet horizontal lines projected across from the corresponding points in the first plan. The third position shows the prism with all its faces and edges making the same angles with the horizontal as in the second position, but with the plan at a different angle with the ground line. The plan then is the same shape and size as in No. 2, and the elevation is found by projecting up to the same heights as shown in the preceding elevation. This principle may be applied to any solid, whether bounded by plane surfaces or curved.

This principle as far as it relates to heights, is the same that was used for profile views. An end view is sometimes necessary before the plan or elevation of an object can be drawn. Suppose that in Fig. 18 we wish to draw the plan and elevation of a triangular prism 3" long, the end of which is an equilateral triangle

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9983-1 1-3-1902 Changed from 1 1/2" length over all, also changed to suit 9983	9983-2 4-1-1902 Changed from No 7 to No 6 taper pin A.B.W.	9983-3 4-1-1902 SHAFT AND ASSEMBLY OF DRUMS TYPE F. CONTROLLER.	Material..... No Regd. Tool No..... Pat. No..... Est. Weight..... Draftsman A.B.W.
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EXAMPLE OF SHOP DRAWING REPRODUCED FROM A BLUE PRINT BY THE COURTESY OF THE BULLOCK ELECTRIC MFG. CO.



$1\frac{1}{2}$ " on each side. The prism is lying on one of its three faces on H, and inclined toward the vertical plane at an angle of 30° . We

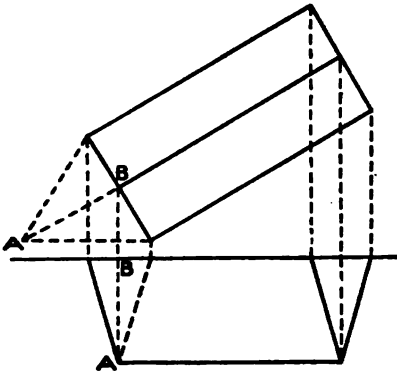


Fig. 19.

are able to draw the plan at once, because the width will be $1\frac{1}{2}$ inches, and the top edge will be projected half way between the other two. The length of the prism will also be shown. Before we can draw the elevation, we must find the height of the top edge. This height, however, must be equal to the altitude of the triangle forming the end of the prism. All that is necessary, then, is to construct an equilateral

triangle $1\frac{1}{2}$ " on each side, and measure its altitude.

A very convenient way to do this is shown in the figure by laying one end of the prism down on H. A similar construction is shown in Fig. 19, but with one face of the prism on V instead of on H.

In all the work thus far the plan has been drawn below and the elevation above. This order is sometimes inverted and the plan put above the elevation, but the plan still remains a top view no matter where placed, so that after some practice it makes but little difference to the draughtsman which method is employed.

SHADE LINES.

It is often the case in machine drawing that certain lines or edges are made heavier than others. These heavy lines are called shade lines, and are used to improve the appearance of the drawing, and also to make clearer in some cases the shape of the object. The shade lines are not put on at random, but according to some system. Several systems are in use, but only that one which seems most consistent will be described. The shade lines are lines or edges separating light faces from dark ones, assuming the light always to come in a direction parallel to the dotted diagonal of the cube shown in Fig. 20. The direction of the light, then, may be represented on H by a line at 45° running

backward to the right and on V by a 45° line sloping downward and to the right. Considering the cube in Fig. 20, if the light comes in the direction indicated, it is evident that the front, left-hand side and top will be light, and the bottom, back and right-hand side dark. On the plan, then, the shade lines will be the back edge 1 2 and the right-hand edge 2 3, because these edges are between light faces and dark ones. On the elevation, since the front is light, and the right-hand side and bottom dark, the edges 3 7 and 8 7 are shaded. As the direction of the light is represented on the plan by 45° lines and on the elevation also by 45° lines,

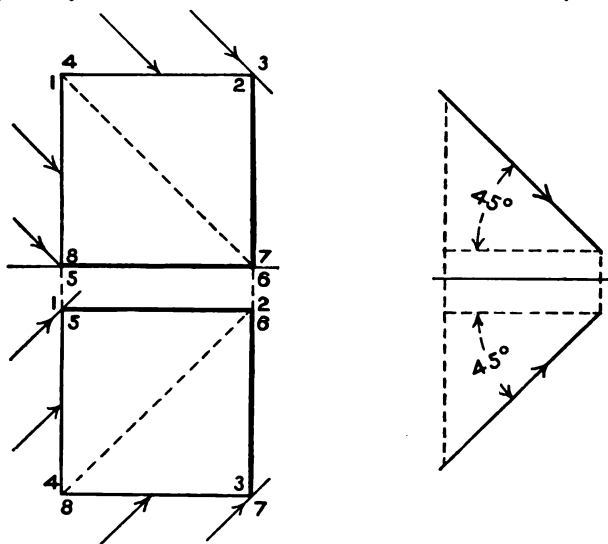


Fig. 20.

we may use the 45° triangle with the T-square to determine the light and dark surfaces, and hence the shade lines. If the object stands on the horizontal plane, the 45° triangle is used on the plan, as shown in Fig. 21, but if the length is perpendicular to the vertical plane, the 45° triangle is used on the elevation, as shown in Fig. 22. This is another way of saying that the 45° triangle is used on that projection of the object which shows the end. By applying the triangle in this way we determine the light and dark surfaces, and then put the shade lines between them. Dotted lines, however, are never shaded, so if a line which is between a light and a dark surface is invisible it is not

shaded. In Fig. 21 the plan shows the end of the solid, hence the 45° triangle is used in the direction indicated by the arrows.

This shows that the light strikes the left-hand face, but not the back or the right-hand. The top is known to be light with-

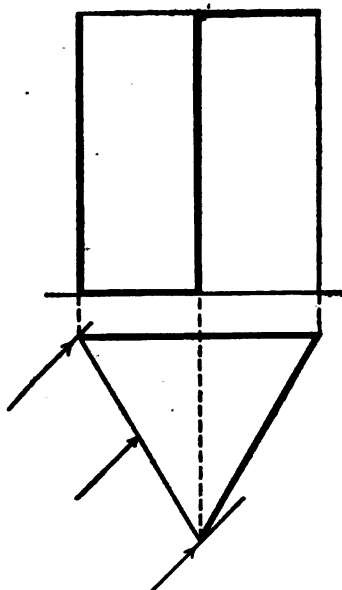


Fig. 21.

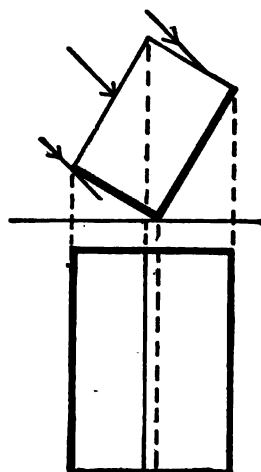


Fig. 22.

out the triangle, as the light comes downward, so the shade edges on the plan are the back and right-hand. On the elevation two faces of the prism are visible; one is light, the other dark, hence the edge between is shaded. The left-hand edge, being between a light face and a dark one is a shade line. The right-hand face is dark, the top of the prism is light, hence the upper edge of this face is a shade line. The right-hand edge is not shaded, because by referring to the plan, it is seen to be between two dark surfaces. In shading a cylinder or a cone the same rule is followed, the only difference being that as the surface is curved, the light is tangent, so an element instead of an edge marks the separation of the dark from the light, and is *not* shaded. The elements of a cylinder or cone should *never* be shaded, but the bases may. In Fig. 23, Nos. 3 and 4, the student should carefully notice the difference between the shading of the cone and cylinder.

If in No. 4 the cone were inverted, the opposite half of the base would be shaded, for then the base would be light, whereas it is now dark. In Nos. 7 and 8 the shade lines of a cylinder and a circular hole are contrasted.

In No. 7 it is clear that the light would strike inside on the further side of the hole, commencing half way where the 45° lines

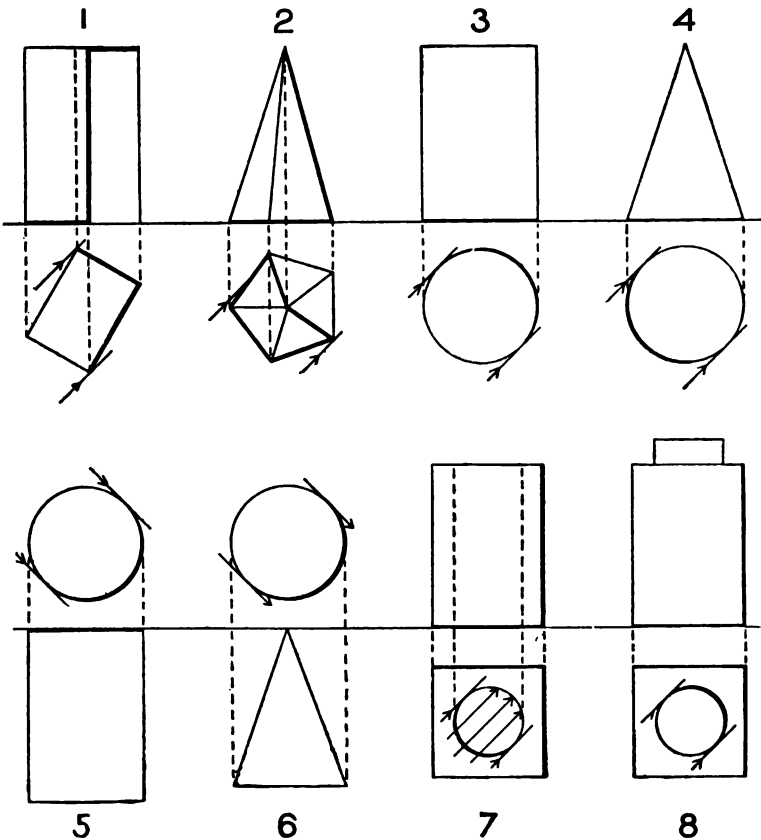


Fig. 23.

are tangent. The other half of the inner surface would be dark, hence the position of the shade line. The shade line then enables us to tell at a glance whether a circle represents a hub or boss, or depression or hole. Fig. 24 represents plan, elevation and profile view of a square prism. Here as before, the view showing the end is the one used to determine the light and dark surfaces, and then the shade lines put in accordingly.

In putting on the shade lines, the extra width of the line is put *inside* the figure, not outside. In shading circles, the shade line is made of varying width, as shown in the figures. The method of obtaining this effect by the compass is to keep the same radius, but to change the center slightly in a direction parallel to the rays of light, as shown at A and B in No. 2 of Fig. 24.

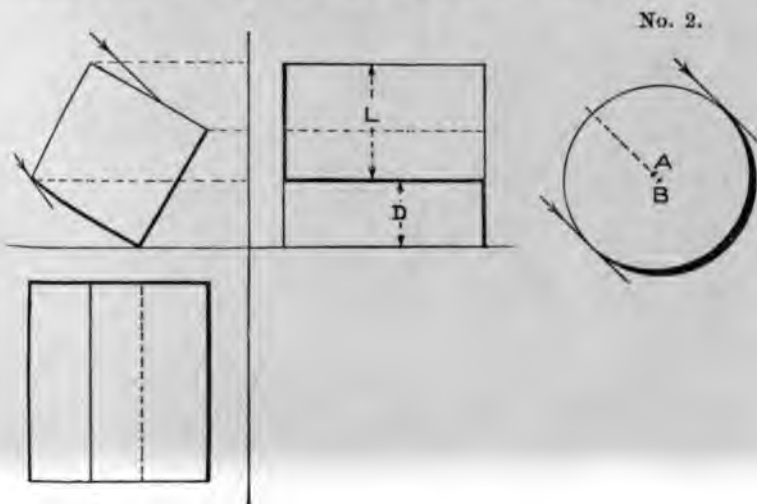


Fig. 24.

INTERSECTION AND DEVELOPMENT.

If one surface meets another at some angle, an intersection is produced. Either surface may be plane, or curved. If both are plane, the intersection is a straight line; if one is curved, the intersection is a curve, except in a few special cases; and if both are curved, the intersection is usually curved.

In the latter case, the entire curve does not always lie in the same planes. If all points of any curve lie in the same plane, it is called a plane curve. A plane intersecting a curved surface must always give either a plane curve or a straight line.

In Fig. 25 a square pyramid is cut by a plane A parallel to the horizontal. This plane cuts from the pyramid a four-sided figure, the four corners of which will be the points where A cuts the four slanting edges of the solid. The plane intersects edge *o b* at point 4^v in elevation. This point must be found in plan vertically below on

the horizontal projection of line $o b$, that is, at point 4^h . Edge $o e$ is directly in front of $o b$, so is shown in elevation as the same line, and plane A intersects $o e$ at point 1^v in elevation, found in plan at 1^h . Points 3 and 2 are obtained in the same way. The intersection is shown in plan as the square 1 2 3 4, which is also its true size as it is parallel to the horizontal plane. In a

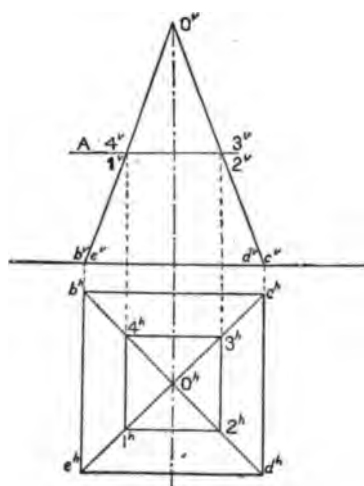


Fig. 25.

similar way the sections are found in Figs. 26 and 27. It will be seen that in these three cases where the planes are parallel to the bases, the sections are of the same shape as the bases, and have their sides parallel to the edges of the bases.

It is an invariable rule that when such a solid is cut by a plane parallel to its base, the section is a figure of the same shape as the base. If then in Fig. 28 a right cone is intersected by a plane parallel to the base the section must be a circle, the center of

which in plan coincides with the apex. The radius must equal $o d$.

In Figs. 29 and 30 the cutting plane is not parallel to the base, hence the intersection will not be of the same shape as the base. The sections are found, however, in exactly the same manner as in the previous figures, by projecting the points where the plane intersects the edges in elevation on to the other view of the same line.

INTERSECTION OF PLANES WITH CONES OR CYLINDERS.

Sections cut by a plane from a cone have already been defined as *conic sections*. These sections may be either of the following: two straight lines, circle, ellipse, parabola, hyperbola. All except the parabola and hyperbola may also be cut from a cylinder.

Methods have previously been given for constructing the

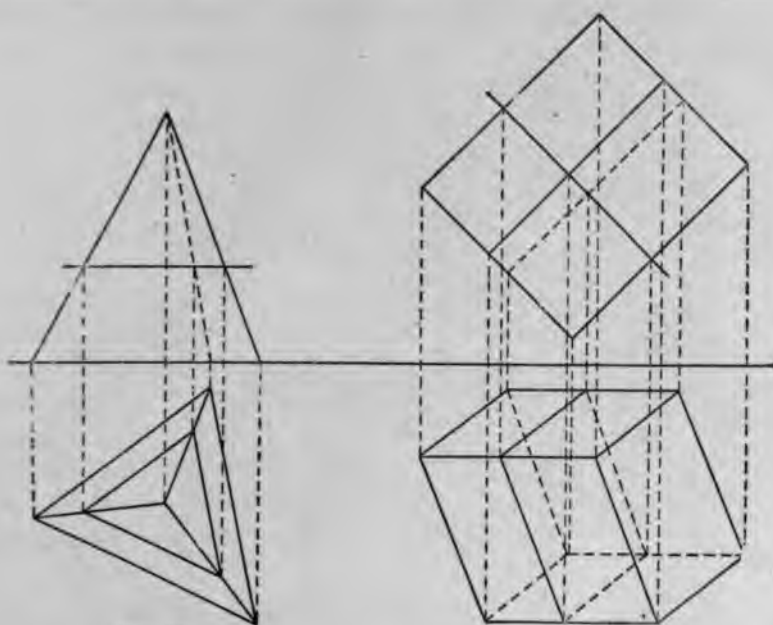


Fig. 26.

Fig. 27.

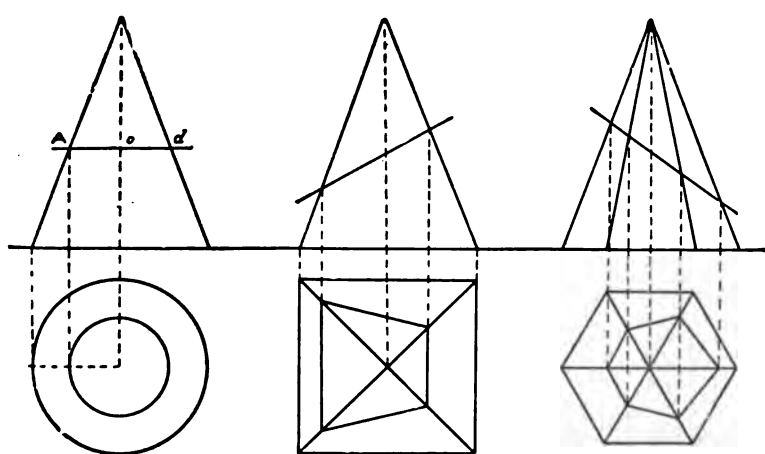


Fig. 28.

Fig. 29.

Fig. 30.

ellipse, parabola and hyperbola without projections; it will now be shown that they may be obtained as actual intersections.

In Fig. 31 the plane cuts the cone obliquely. To find points on the curve in plan take a series of horizontal planes

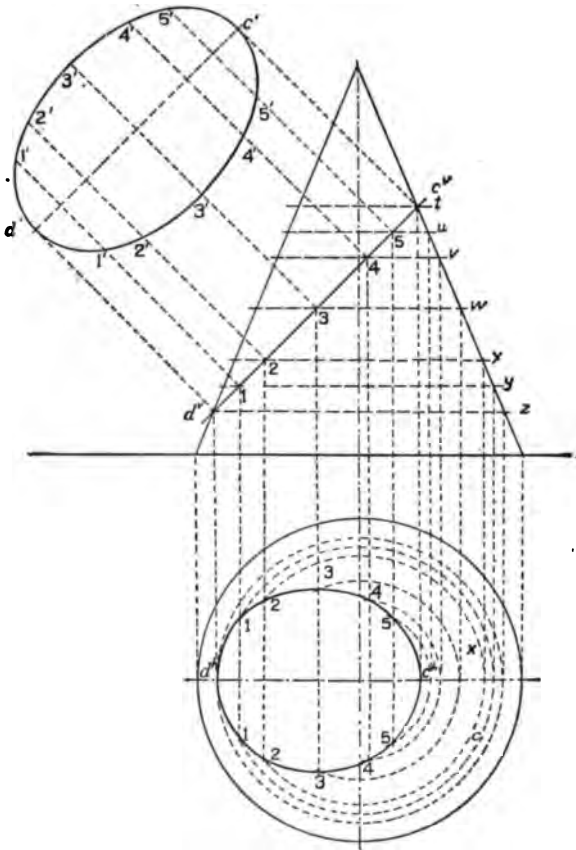


Fig. 31.

x, y, z etc., between points c^v and d^v . One of these planes, as w , should be taken through the center of c, d . The points c and d must be points on the curve, since the plane cuts the two contour elements at these points. The horizontal projections of the contour elements will be found in a horizontal line passing through the center of the base; hence the horizontal projection of c and d will be found on this center line, and will be the extreme ends of the curve. Contour elements are those forming the outline.

The plane x cuts the surface of the cone in a circle, as it is parallel to the base, and the diameter of the circle is the distance between the points where x crosses the two contour elements. This circle, lettered x on the plan, has its center at the horizontal projection of the apex. The circle x and the curve cut by the plane are both on the surface of the cone, and their vertical projections intersect at the point 2. Also the circle x and the curve must cross twice, once on the front of the cone and once on the back. Point 2 then represents two points which are shown in plan directly beneath on the circle x , and are points on the required intersection. Planes y and z , and as many more as may be necessary to determine the curve accurately, are used in the same way. The curve found is an ellipse. The student will readily see that the true size of this ellipse is not shown in the plan, for the plane containing the curve is not parallel to the horizontal.

In order to find the **actual size** of the ellipse, it is necessary to place its plane in a position parallel either to the vertical or to the horizontal. The actual length of the long diameter of the ellipse must be shown in elevation, $e^v d^v$, because the line is parallel to the vertical plane. The plane of the ellipse then may be revolved about $e^v d^v$ as an axis until it becomes parallel to V , when its true size will be shown. For the sake of clearness of construction, $e^v d^v$ is imagined moved over to the position $e' d'$, parallel to $e^v d^v$. The lines 1—1, 2—2, 3—3 on the plan show the true width of the ellipse, as these lines are parallel to H , but are projected closer together than their actual distances. In elevation these lines are shown as the points 1, 2, 3, at their true distance apart. Hence if the ellipse is revolved around its axis $e^v d^v$, the distances 1—1, 2—2, 3—3 will appear perpendicular to $e^v d^v$, and the true size of the figure be shown. This construction is made on the left, where 1'—1', 2'—2' and 3'—3' are equal in length to 1—1, 2—2, 3—3 on the plan.

In Fig. 32 a plane cuts a cylinder obliquely. This is a simpler case, as the horizontal projection of the curve coincides with the base of the cylinder. To obtain the true size of the section, which is an ellipse, any number of points are assumed on the plan and projected up on the cutting plane, at 1, 2, 3, etc.

The lines drawn through these points perpendicular to 1 7 are made equal in length to the corresponding distances $2'-2'$, $3'-3'$ etc., on the plan, because $2'-2'$ is the true width of curve at 2.

If a cone is intersected by a plane which is parallel to only

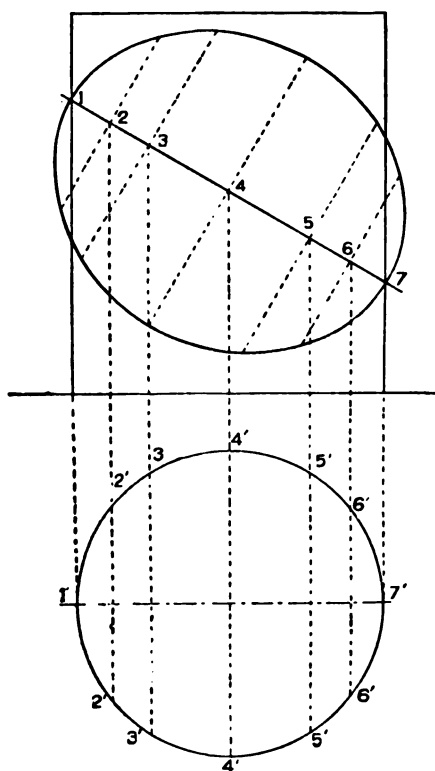


Fig. 32.

one of the elements, as in Fig. 33, the resulting curve is the parabola, the construction of which is exactly similar to that for the ellipse as given in Fig. 31. If the intersecting plane is parallel to more than one element, or is parallel to the axis of the cone, a hyperbola is produced.

In Fig. 34, the vertical plane A is parallel to the axis of the cone. In this instance the curve when found will appear in its true size, as plane A is parallel to the vertical. Observe that the highest point of the curve is found by drawing the circle X on the plan tangent to the given plane. One of the points where this circle crosses the diameter is projected up to the contour element of the

cone, and the horizontal plane X drawn. Intermediate planes Y, Z, etc., are chosen, and corresponding circles drawn in plan. The points where these circles are crossed by the plane A are points on the curve, and these points are projected up to the elevation on the planes Y, Z, etc.

DEVELOPMENTS.

The development of a surface is the true size and shape of the surface extended or spread out on a plane. If the surface to be developed is of such a character that it may be flattened out

without tearing or folding, we obtain an exact development, as in case of a cone or cylinder, prism or pyramid. If this cannot be done, as with the sphere, the development is only approximate.

In order to find the development of the rectangular prism in Fig 35, the back face, 1 2 7 6, is supposed to be placed in contact

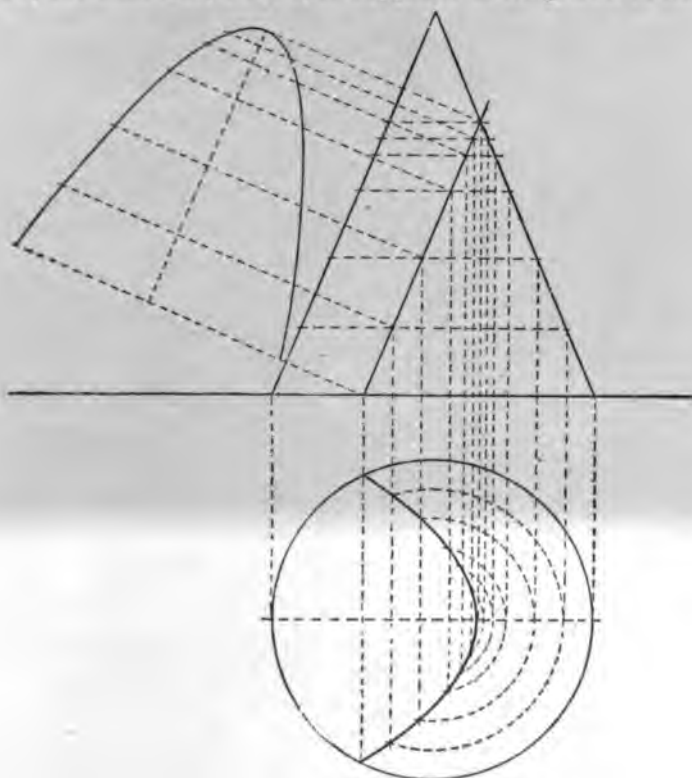


Fig. 33.

with some plane, then the prism turned on the edge 2 7 until the side 2 3 8 7 is in contact with the same plane, then this continued until all four faces have been placed on the same plane. The rectangles 1 4 3 2 and 6 7 8 5 are for the top and bottom respectively. The development then is the exact size and shape of a covering for the prism. If a rectangular hole is cut through the prism, the openings in the front and back faces will be shown in the development in the centers of the two broad faces.

The development of a right prism, then, consists of as many

rectangles joined together as the prism has sides, these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases. It will be found helpful in developing a solid to number or letter all of the corners on the

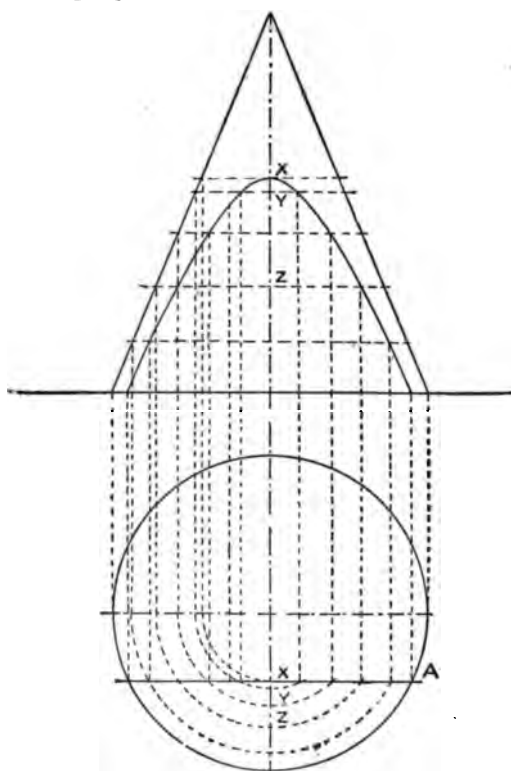


Fig. 34.

projections, then designate each face when developed in the same way as in the figure.

If a cone be placed on its side on a plane surface, one element will rest on the surface. If now the cone be rolled on the plane, the vertex remaining stationary, until the same element is in contact again, the space rolled over will represent the development of the convex surface of the cone. A, Fig. 36, is a cone cut by a plane parallel to the base. In B, let the vertex of the cone be

placed at V, and one element of the cone coincide with V A I. The length of this element is taken from the elevation A, of either contour element. All of the elements of the cone are of the same length, so when the cone is rolled each point of the base as it touches the plane will be at the same distance from the vertex. From this it follows that the development of the base will be the arc of a circle of radius equal to the length of an element. To find the length of this arc which is equal to the distance around the base, divide the plan of the circumference of the base into any number of equal parts, as twelve, then

with the length of one of these parts as radius, lay off twelve spaces, 1.....13, join 1 and 13 with V, and the sector is the development of the cone from vertex to base. To represent on the development

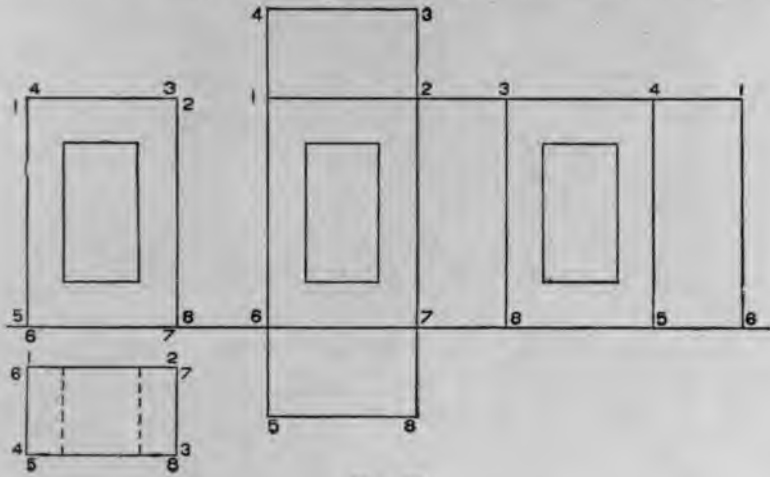


Fig. 35.

the circle cut by the section plane, take as radius the length of the element from the vertex to D, and with V as center describe

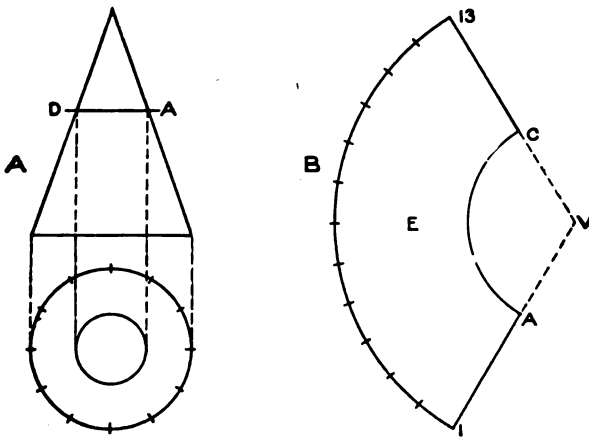


Fig. 36.

an arc. The development of the frustum of the cone will be the portion of the circular ring. This of course does not include the

development of the bases, which would be simply two circles the same sizes as shown in plan.

A and B, Fig. 37, represent the plan and elevation of a regular triangular pyramid and its development. If face C is placed on the plane its true size will be shown at C in the development. The true length of the base of triangle C is shown in the plan. The slanting edges, however, not being parallel to the vertical, are not shown in elevation in their true length. It becomes necessary then, to find the true length of one of these edges as shown in Fig. 6, after which the triangle may be drawn in its full size at C in the development. As the pyramid is regular, three equal triangles as shown developed at C, D and E, together with the base F, constitute the development.

If a right circular cylinder is to be developed, or rolled upon a plane, the elements, being parallel, will appear as parallel lines,

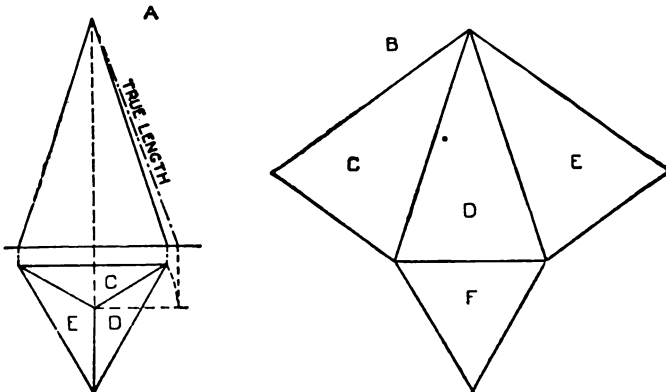


Fig. 37.

and the base, being perpendicular to the elements, will develop as a straight line perpendicular to the elements. The width of the development will be the distance around the cylinder, or the circumference of the base. The base of the cylinder in Fig. 38, is divided into twelve equal parts, 1 2 3, etc. Commencing at point 1 on the development these twelve equal spaces are laid along the straight line, giving the development of the base of the cylinder, and the total width. To find the development of the curve cut by the oblique plane, draw in elevation the elements corresponding to the various divisions of the base, and note the points

where they intersect the oblique plane. As we roll the cylinder beginning at point 1, the successive elements 1, 12, 11, etc., will appear at equal distances apart, and equal in length to the lengths of the same elements in elevation. Thus point number 10 on the development of the curve is found by projecting horizontally across from 10 in elevation. It will be seen that the curve is symmetrical, the half on the left of 7 being similar to that on the right. The development of any curve whatever on the surface of the cylinder may be found in the same manner.

The principle of cylinder development is used in laying out elbow joints, pipe ends cut off obliquely, etc. In Fig. 39 is shown plan and elevation of a three-piece elbow and collar, and develop-

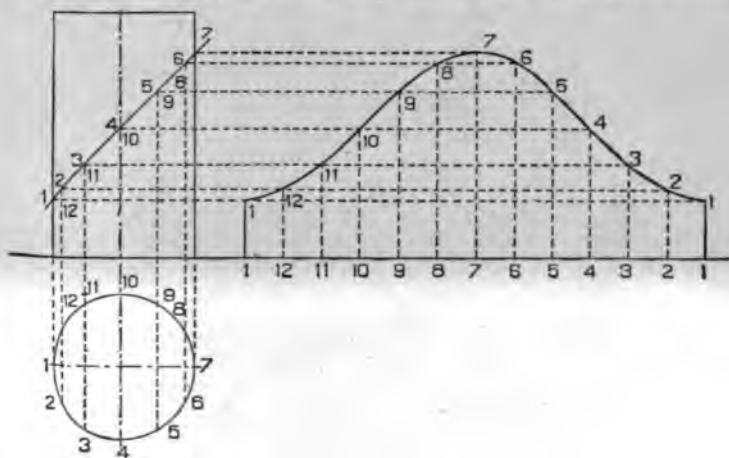


Fig. 38.

ments of the four pieces. In order to construct the various parts making up the joint, it is necessary to know what shape and size must be marked out on the flat sheet metal so that when cut out and rolled up the three pieces will form cylinders with the ends fitting together as required. Knowing the kind of elbow desired, we first draw the plan and elevation, and from these make the developments. Let the lengths of the three pieces A, B and C be the same on the upper outside contour of the elbow, the piece B at an angle of 45° ; the joint between A and B bisects the angle between the two lengths, and in the same way the joint between B and C. The lengths A and C will then be the same,

and one pattern will answer for both. The development of A is made exactly as just explained for Fig. 38, and this is also the development of C.

It should be borne in mind that in developing a cylinder we must always have a base at right angles to the elements, and if the cylinder as given does not have such a base, it becomes necessary to cut the cylinder by a plane perpendicular to the elements, and use the intersection as a base. This point must be clearly understood in order to proceed intelligently. A section at right angles to the elements is the only section which will unroll in a

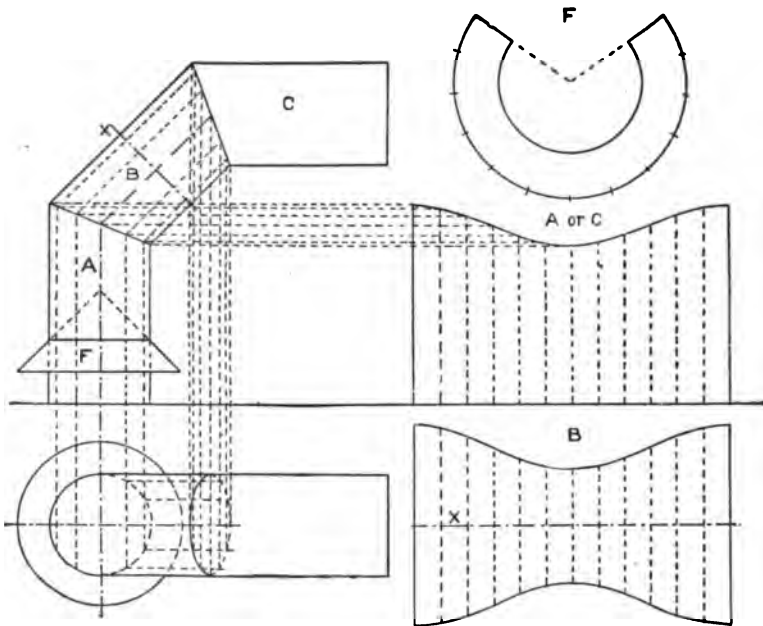
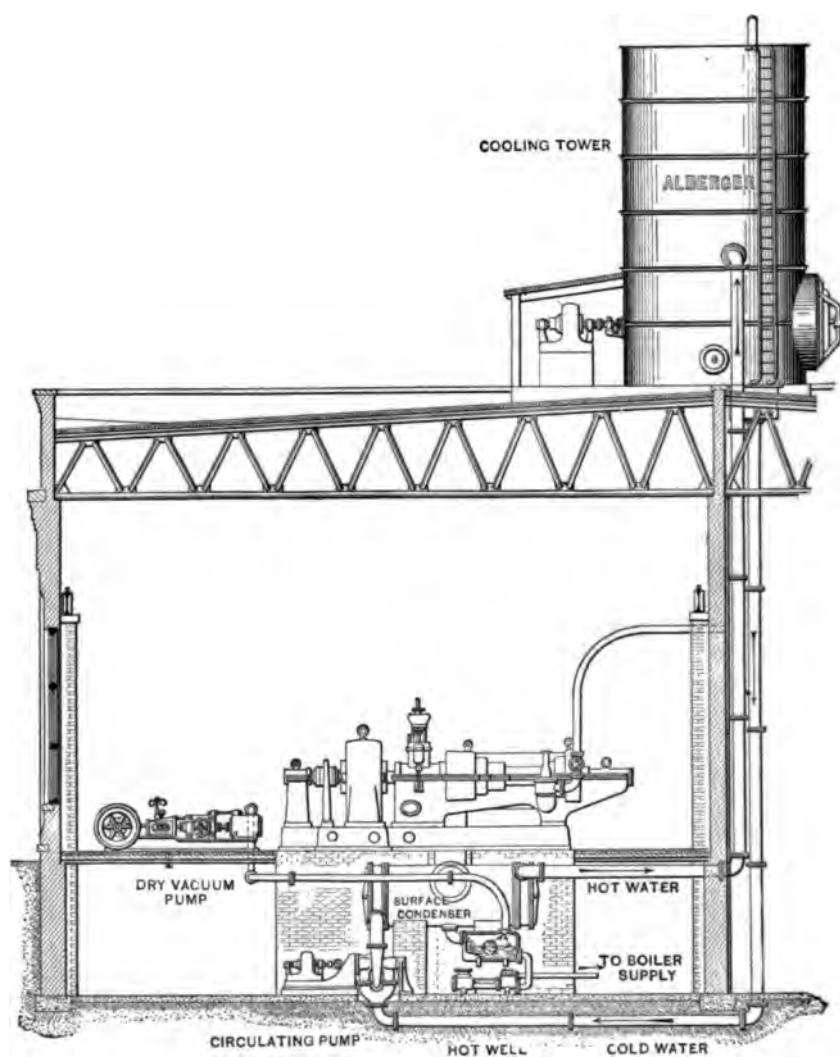


Fig. 30.

straight line, and is therefore the section from which we must work in developing other sections. As B has neither end at right angles to its length, the plane X is drawn at the middle and perpendicular to the length. B is the same diameter pipe as C and A, so the section cut by X will be a circle of the same diameter as the base of A, and its development is shown at X.

From the points where the elements drawn on the elevation of A meet the joint between A and B, elements are drawn on B,





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which are equally spaced around B the same as on A. The spaces then laid off along X are the same as given on the plan of A. Commencing with the left-hand element in B, the length of the upper element between X and the top corner of the elbow is laid off above X, giving the first point in the development of the end of B fitting with C. The lengths of the other elements in the elevation of B are measured in the same way and laid off from X. The development of the other end of the piece B is laid off below X, using the same distances, since X is half way between the ends. The development of the collar is simply the development of the frustum of a cone, which has already been explained, Fig. 36. The joint between B and C is shown in plan as an ellipse, the construction of which the student should be able to understand from a study of the figure.

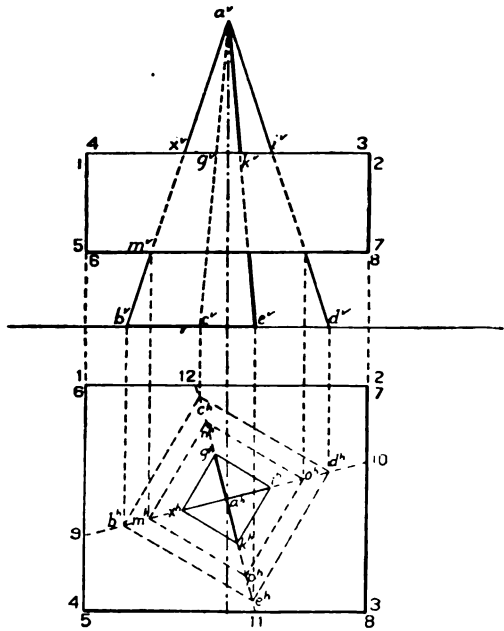


Fig. 40.

The intersection of a rectangular prism and pyramid is shown in Fig. 40. The base $b c d e$ of the pyramid is shown dotted in plan, as it is hidden by the prism. All four edges of the pyramid pass through the top of the prism, 1, 2, 3, 4. As the top of the prism is a horizontal plane, the edges of the pyramid are shown passing through the top in elevation at $x^e g^r k^r i^r$. These four points might be projected to the plan on the four edges of the pyramid; but it is unnecessary to project more than one, since the general principle applies here that if a cone, pyramid, prism or cylinder be cut by a plane parallel to the base, the section is a figure parallel and similar to the base. The one point x^e is therefore projected down to $a b$ in plan, giving x^b , and with this as

one corner, the square $x^h g^h i^h k^h$ is drawn, its sides parallel to the edges of the base. This square is the intersection of the pyramid with the top of the prism.

The intersection of the pyramid with the bottom of the prism is found in like manner, by taking the point where one edge of the pyramid as a^b passes through the bottom of the prism shown in elevation as point m^v , projecting down to m^h on $a^h b^h$, and drawing the square $m^h n^h o^h p^h$ parallel to the base of the pyramid. These two squares constitute the entire intersection of the two solids, the pyramid going through the bottom and coming out at the top of the prism. As much of the slanting edges of the

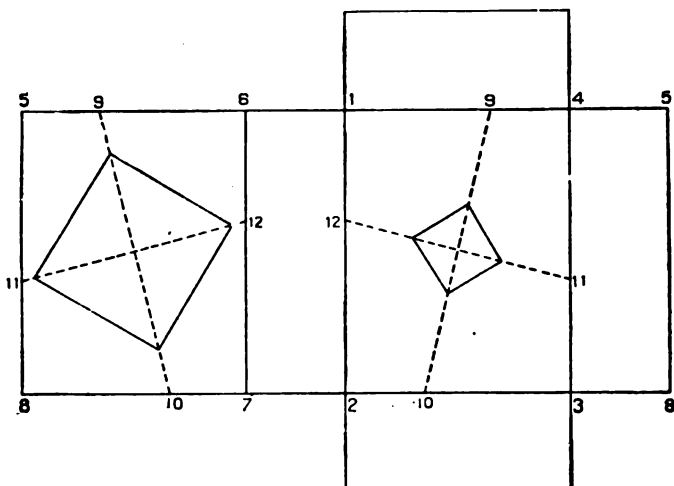


Fig. 41.

pyramid as are above the prism will be seen in plan, appearing as the diagonals of the small square, and the rest of the pyramid, being below the top surface of the prism, will be dotted in plan.

Fig. 41 is the development of the rectangular prism, showing the openings in the top and bottom surfaces through which the pyramid passed. The development of the top and bottom, back and front faces will be four rectangles joined together, the same sizes as the respective faces. Commencing with the bottom face 5 6 7 8, next would come the back face 6 1 2 7, then the top, etc. The rectangles at the ends of the top face 1 2 3 4 are the ends of the prism. These might have been joined on any other

face as well. Now find the development of the square in the bottom 5 6 7 8. As the size will be the same as in projection, it only remains to determine its position. This position, however, will have the same relation to the sides of the rectangle as in the plan. The center of the square in this case is in the center of the face. To transfer the diagonals of the square to the development, extend them in plan to intersect the edges of the prism in points 9, 10, 11 and 12. Take the distance from 5 to 9 along the edge 5 6, and lay it on the development from 5 along 5 6, giving point 9. Point 10 located in the same way and connected with 9, gives the position of one diagonal. The other diagonal is obtained in a similar way, then the square constructed on these diagonals. The same method is used for locating the small square on the top face.

If the intersection of a cylinder and prism is to be found, we may either obtain the points where elements of the cylinder pierce the prism, or where edges and lines parallel to edges on the surface of the prism cut the cylinder.

A series of parallel planes may also be taken cutting curves from the cylinder and straight lines from the prism; the intersections give points on the intersection of the two solids.

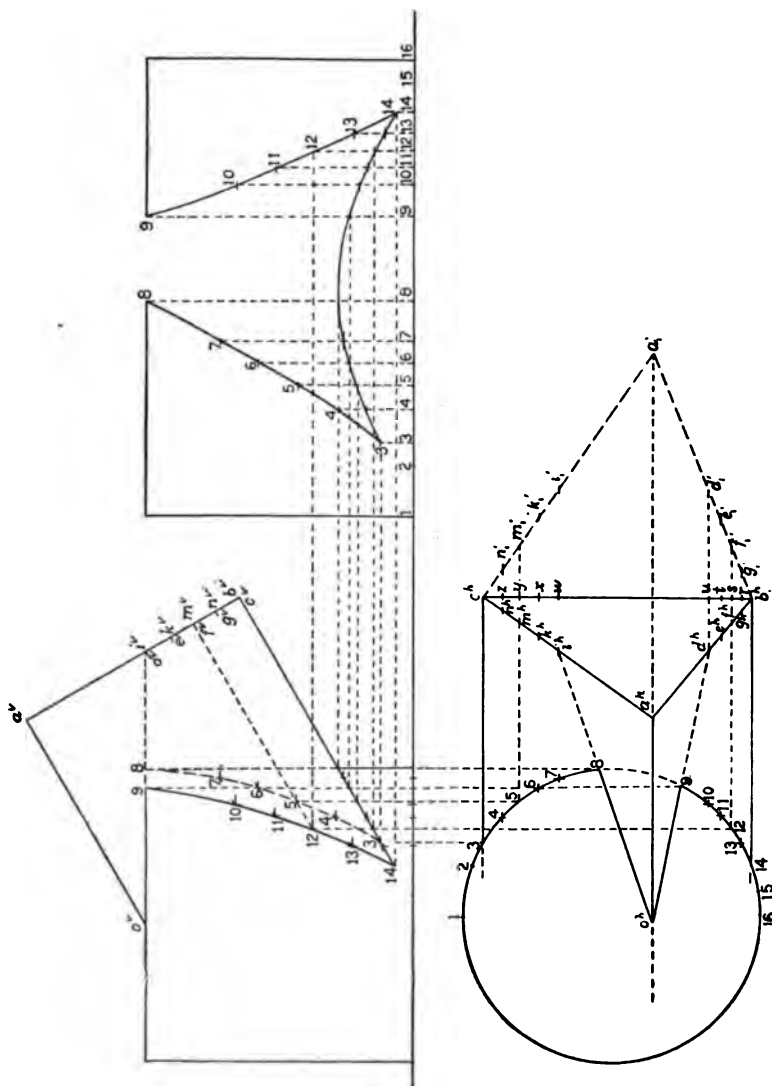
Fig. 42 represents a triangular prism intersecting a cylinder. The axis of the prism is parallel to V and inclined to H. Starting with the size and shape of the base, this is laid off at $a' b' c'$, and the altitude of the triangle taken and laid off at $a' d'$ in elevation, making right angles with the inclination of the axis to H. The plan of the prism is then constructed. To find the intersection of the two solids, lines are drawn on the surface of the prism parallel to the length and the points where these lines and the edges pierce the cylinder are obtained and joined, giving the curve.

The top edge of the prism goes into the top of the cylinder. This point will be shown in elevation, since the top of the cylinder is a plane parallel to H and perpendicular to V, and therefore projected on V as a straight line. The upper edge, then, is found to pass into the top of the cylinder at point $a' d'$ and $e' f'$. The intersection of the two upper faces of the prism with the top of the cylinder will be straight lines drawn from point a' and will be shown in plan. If we can find where another line of the surface $a' b' 14$ pierces the upper base of the cylinder, this point joined

with o will determine the intersection of this face with the top of the cylinder. A surface may always be produced, if necessary to find an intersection.

Edge $a b$ pierces the plane of the top of the cylinder at point

Fig. 43.



d , seen in elevation; therefore the line joining this point with o is the intersection of one upper face of the prism with the upper

base of the cylinder. The only part of this line needed, of course, is within the actual limits of the base, that is $o 9$. The intersection $o 8$ of the other top face is found by the same method. On the convex surface of the cylinder there will be three curves, one for each face of the prism. Points 8 and 9 on the upper base of the cylinder, will be where the curves for the two upper faces will begin. The point d is found on the revolved position of the base at d_1 , and $d_1 b$ is divided into the equal parts $d_1 - e_1$, $e_1 - f_1$, etc., which revolve back to d^h , e^h , f^h and g^h . The divisions are made equal merely for convenience in developing. The vertical projections of d , e , etc., are found on the vertical projection of $a b$, directly above d^h , e^h , etc., or may be found by taking from the revolved position of the base, the perpendiculars from d_1 , e_1 , etc., to $a^h b^h$ and laying them off in elevation from b^v along $b^v a^v$. Lines such as $f 12$, $m 5$, etc., parallel to $a o$ are drawn in plan and elevation. Points i^h , k^h , m^h , n^h are taken directly behind d^h , e^h , f^h , g^h hence their vertical projections coincide. Points n_1 , m_1 , k_1 and i_1 are formed by projecting across from n^h , m^h , k^h and i^h .

The convex surface of the cylinder is perpendicular to H , so the points where the lines on the prism pierce it will be projected on plan as the points where these lines cross the circle. 14 , 13 , 12 , 11 , ... 3 . The vertical projections of these points are found on the corresponding lines in elevation, and the curves drawn through. The curve 3 , 4 , ... 8 must be dotted, as it is on the back of the cylinder. The under face of the prism, which ends with the line $h e$, is perpendicular to the vertical plane, so the curve of intersection will be projected on V as a straight line. Point 14 is one end of this curve. 3 the other end, and the curve is projected in elevation as the straight line from 14 to the point where the lower edge of the prism crosses the contour element of the cylinder.

Fig. 43 gives the development of the right-hand half of the cylinder, beginning with number 1 . As previously explained, the distance between the elements is shown in the plan, as $1-2$, $2-3$, $3-4$ and so on. These spaces are laid off in the development along a straight line representing the development of the base, and from these points the elements are drawn perpendicularly.

The lengths of the elements in the development from the base to the curve are exactly the same as on the elevation, as the

elevation gives the true lengths. If then the development of the base is laid off along the same straight line as the vertical projection of the base, the points in elevation may be projected across with the T-square to the corresponding elements in the development. The points on the curve cut by the under face of the prism are on the same elements as the other curves, and their vertical projections are on the under edge of the prism, hence these points are projected across for the development of the lower curve.

In Fig. 44 is given the development of the prism from the right-hand end as far as the intersection with the cylinder, begin-

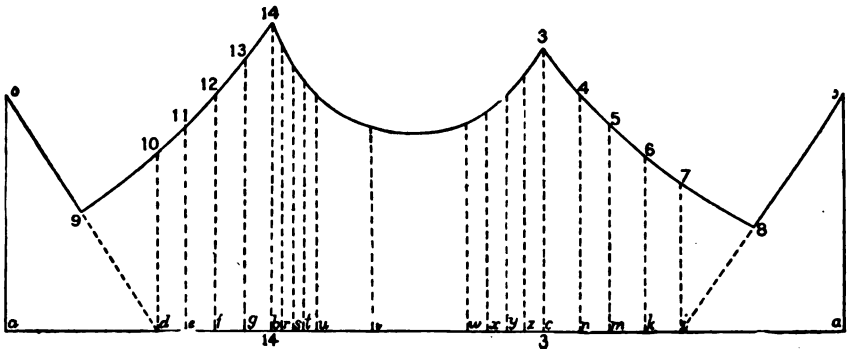


Fig. 44.

ning at the left with the top edge $a o$, the straight line $a b c a$ being the development of the base. As this must be the actual distance around the base, the length is taken from the true size of the base, $a_1 b_1 c_1 h$. The parallel lines drawn on the surfaces of the prism must appear on the development their true distances apart, hence the distances $a_1 d_1, d_1 e_1$, etc., are made equal to $a d, d e$, etc. on the development. The actual distances between the parallel lines on the bottom face of the prism are shown along the edge of the base, $b_1 h c_1 h$. Perpendicular lines are drawn from the points of division on the development.

The position of the developed curve is found by laying off the true lengths on the perpendiculars. These true lengths (of the parallel lines) are not shown in plan, as the lines are not parallel to the horizontal plane, but are found in elevation. The length oa on the development is equal to $a^v o^v, d 10$ to $d^v 10$, and

so on for all the rest. Point 9 is found as follows: on the projections, the straight line from o to d passes through point 9, and the true distance from o to 9 is shown in plan. All that is necessary, then, is to connect o and d on the development, and lay off from o the distance o^h9 . Number 8 is found in the same way.

ISOMETRIC PROJECTION.

Heretofore an object has been represented by two or more projections. Another system, called **isometrical drawing**, is used to show in one view the three dimensions of an object, length (or height), breadth, and thickness. An isometrical drawing of an object, as a cube, is called for brevity the "isometric" of the cube.

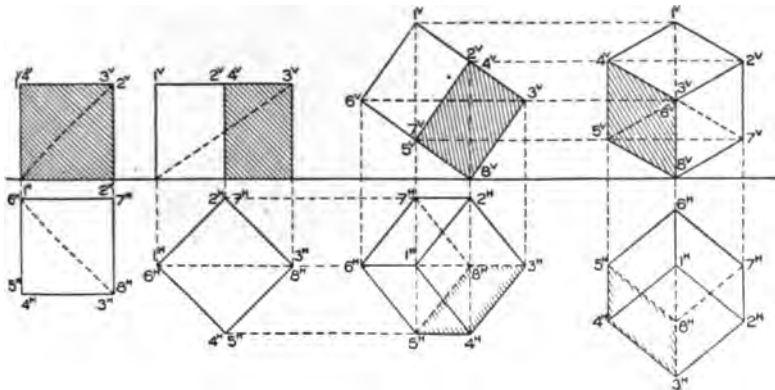


Fig. 45.

To obtain a view which shows the three dimensions in such a way that measurements can be taken from them, draw the cube in the simple position shown at the left of Fig. 45, in which it rests on H with two faces parallel to V ; the diagonal from the front upper right-hand corner to the back lower left-hand corner is indicated by the dotted line. Swing the cube around until the diagonal is parallel with V as shown in the second position. Here the front face is at the right. In the third position the lower end of the diagonal has been raised so that it is parallel to H , becoming thus parallel to both planes. The plan is found by the principles of projection, from the elevation and the preceding plan. The front face is now the lower of the two faces shown in the elevation. From this position the cube is swung around, using the corner

resting on the H as a pivot, until the diagonal is perpendicular to V but still parallel to H . The plan remains the same, except as regards position; while the elevation, obtained by projecting across from the previous elevation, gives the isometrical projection of the cube. The front face is now at the left.

In the last position, as one diagonal is perpendicular to V , it follows that all the faces of the cube make equal angles with V , hence are projected on that plane as equal parallelograms. For the same reason all the edges of the cube are projected in elevation in equal lengths, but, being inclined to V , appear shorter than they actually are on the object. Since they are all equally foreshortened and since a drawing may be made at any scale, it is customary to

make all the isometrical lines of a drawing full length. This will give the same proportions, and is much the simplest method. Herein lies the distinction between an isometrical projection and an isometric drawing.

It will be noticed that the figure can be inscribed in a circle, and that the outline is a perfect hexagon. Hence the lines showing breadth and length are 30° lines, while those showing height are vertical.

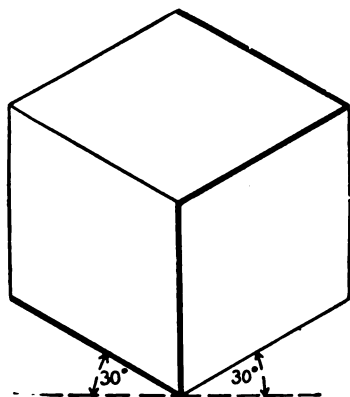


Fig. 46.

Fig. 46 shows the isometric of a cube, 1 inch square. All of the edges are shown in their true length, hence all the surfaces appear of the same size. In the figure the edges of the base are inclined at 30° with a T-square line, but this is not always the case. For rectangular objects, such as prisms, cubes, etc., the base edges are at 30° only when the prism or cube is supposed to be in the simplest possible position. The cube in Fig. 46 is supposed to be in the position indicated by plan and elevation in Fig. 47, that is, standing on its base, with two faces parallel to the vertical plane.

If the isometric of the cube in the position of Fig. 48 were required, it could not be drawn with the base edges at 30° ; neither

would these edges appear in their true lengths. It follows, then, that in isometrical drawing, true lengths appear only as 30° lines or as vertical lines. Edges or lines that in actual projection are either parallel to the ground line or perpendicular to V, are drawn in isometric as 30° lines, full length; and those that are actually vertical are made vertical in isometric, also full length.

In Fig. 45, lines such as the front vertical edges of the cube and the two base edges are called the three **isometric axes**. The isometric of objects in oblique positions, as in Fig. 48, can be con-

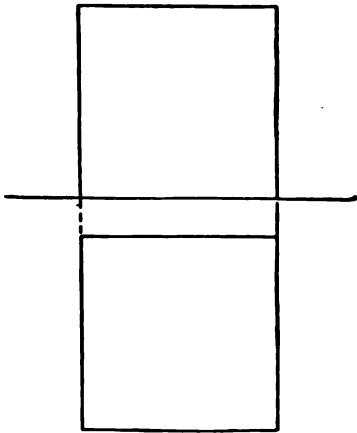


Fig. 47.

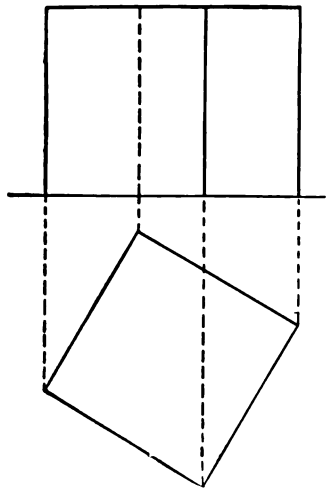


Fig. 48.

structed only by reference to their projections, by methods which will be explained later.

In isometric drawing small rectangular objects are more satisfactorily represented than large curved ones. In woodwork, mortises and joints and various parts of framing are well shown in isometric. This system is used also to give a kind of bird's-eye view of the mills or factories. It is also used in making sketches of small rectangular pieces of machinery, where it is desirable to give shape and dimensions in one view.

In isometric drawing the **direction of the ray of light** is parallel to that diagonal of a cube which runs from the upper left corner to the lower right corner, as 4v-7v in the last elevation of Fig. 45. This diagonal is at 30° ; hence in isometrical drawing the direction of the light is at 30° downward to the right. From

this it follows that the top and two left-hand faces of the cube are light, the others dark. This explains the shade lines in Fig. 45.

In Fig. 45, the top end of the diagonal which is parallel to the ray of light in the first position is marked 4, and traced through to the last or isometrical projection, 4^v . It will be seen that face $3^v 4^v 5^v 8^v$ of the isometric projection is the front face of the cube in the first view; hence we may consider the left front face of the isometric cube as the front. This is not absolutely necessary, but by so doing the isometric shade edges are exactly the same as on the original projection.

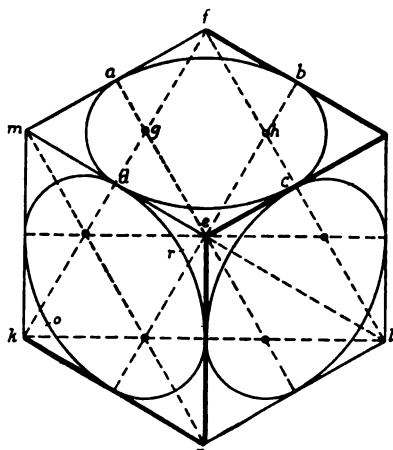


Fig. 49.

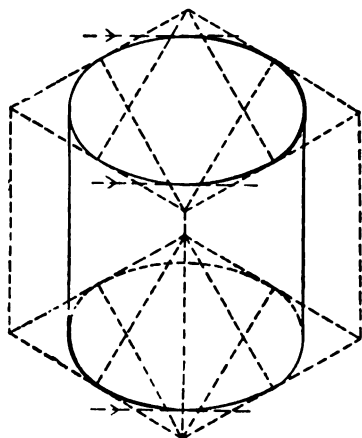


Fig. 50.

Fig. 49 shows a cube with circles inscribed in the top and two side faces. The isometric of a circle is an ellipse, the exact construction of which would necessitate finding a number of points; for this reason an approximate construction by arcs of circles is often made. In the method of Fig. 49, four centers are used. Considering the upper face of the cube, lines are drawn from the obtuse angles f and e , to the centers of the opposite sides. The intersections of these lines give points g and h , which serve as centers for the ends of the ellipse. With center g and radius $g a$, the arc $a d$ is drawn; and with f as center and radius $f d$, the arc $d e$ is described, and the ellipse finished by using centers h and e . This construction is applied to all three faces.

The intersections of these lines give points g and h , which serve as centers for the ends of the ellipse. With center g and radius $g a$, the arc $a d$ is drawn; and with f as center and radius $f d$, the arc $d e$ is described, and the ellipse finished by using centers h and e . This construction is applied to all three faces.

Fig. 50 is the isometric of a cylinder standing on its base.

Notice that the shade line on the top begins and ends where T-square lines would be tangent to the curve, and similarly in the case of the part shown on the base. The explanation of the shade is very similar to that in projections. Given in projections a cylinder standing on its base, the plan is a circle, and the shade line is determined by applying the 45° triangle tangent to the circle. This is done because the 45° line is the projection of the ray of light on the plane of the base.

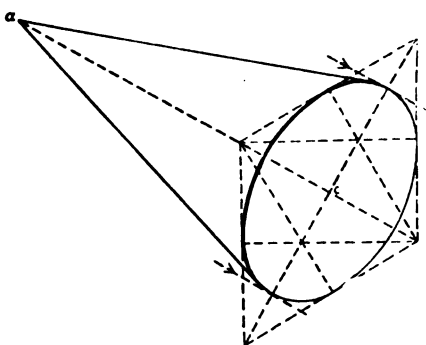


Fig. 51.

In Fig. 49, the diagonal $m l$ may represent the ray of light and its projection on the base is seen to be $k l$, the diagonal of the base, a T-square line. Hence, for the cylinder of Fig. 50, apply tangent to the base and also to the top a line parallel to the projection of the ray of light on these planes, that is, a T-square line, and this will mark the beginning and ending of the shade line.

In Fig. 49 the projection of the ray of light diagonal $m l$ on the right-hand face is $e l$, a 30° line; hence, in Fig. 51, where the base is similarly placed, apply the 30° triangle tangent as indicated, determining the shade line of the base. If the ellipse on the left-hand face of the cube were the base of a cone or cylinder extending backward to the right, the same principle would be used.

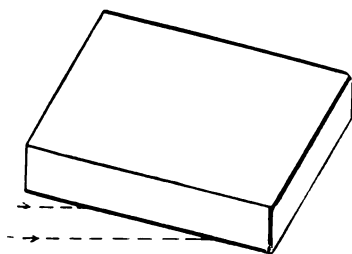


Fig. 52.

The projection of the cube diagonal $m l$ on that face is $m n$, a 60° line; hence the 60° triangle would be used tangent to the base in this last supposed case, giving the ends of the shade line at points o and r . Figs. 52, 53 and 54 illustrate the same idea with respect to prisms, the direction of the projection of the ray of light on the plane of the base being used in each case to determine the light and dark faces and hence the shade lines.

In Fig. 52 a prism is represented standing on its base, so that the projection of the cube diagonal on the base (that is, a T-square line) is used to determine the light and dark faces as shown.

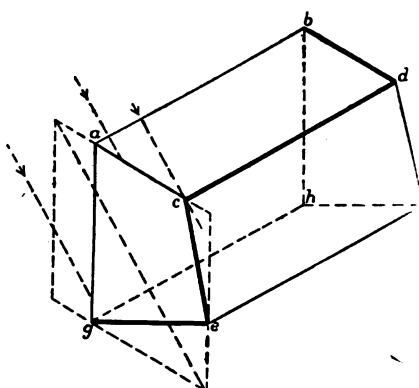


Fig. 53.

The prism in Fig. 53 has for its base a trapezium. The projection of the ray of light on this end is parallel to the diagonal of the face; hence the 60° triangle applied parallel to this diagonal shows that faces $a c d b$ and $a g h b$ are light, while $c e f d$ and $g e f h$ are dark, hence the shade lines as shown.

The application in Fig. 54 is the same, the only difference being in the position of the prism, and the consequent difference in the direction of the diagonal.

Fig. 55 represents a block with smaller blocks projecting from three faces.

Fig. 56 shows a framework of three pieces, two at right angles and a slanting brace. The horizontal piece is mortised into the upright, as indicated by the dotted lines. In Fig. 57 the isometric outline of a house is represented, showing a dormer window and a partial hip roof; $a b$ is a hip rafter, $c d$ a valley. Let the pitch of the main roof be shown at B, and let m be the middle point of the top of the end wall of the house. Then, by measuring vertically up a distance $m l$ equal to the vertical height $a n$ shown at B, a point on the line of the ridge will be found at l . Line $l i$ is equal to $b h$, and $i h$ is then drawn. Let the pitch of

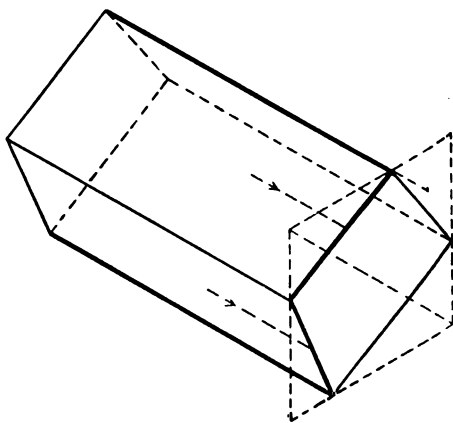


Fig. 54.

the end roof be given at A. This shows that the peak of the roof, or the end a of the ridge, will be back from the end wall a distance equal to the base of the triangle at A. Hence lay off from l this distance, giving point a , and join a with b and x .

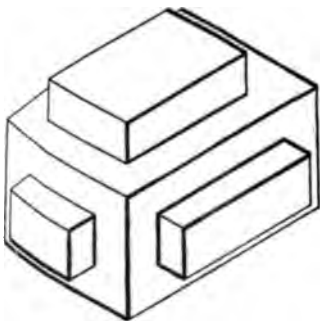


Fig. 55.

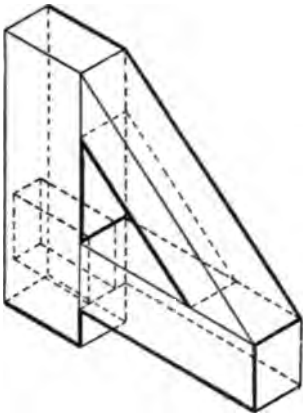


Fig. 56.

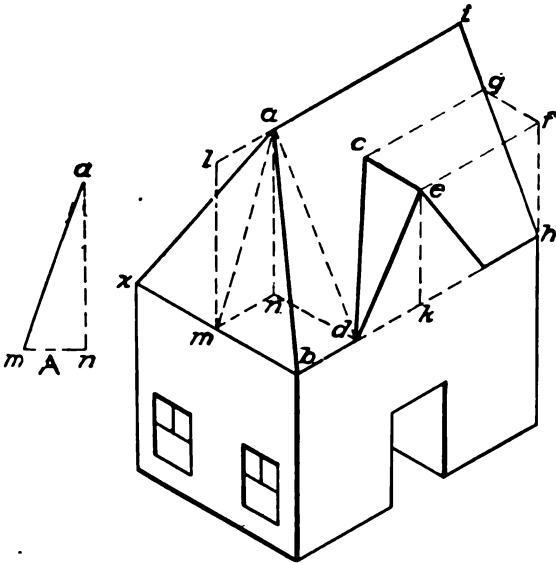
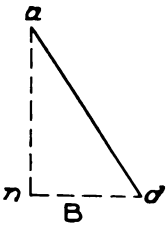


Fig. 57.



The height $k e$ of the ridge of the dormer roof is known, and we must find where this ridge will meet the main roof. The ridge must be a 30° line as it runs parallel to the end wall of the house

and to the ground. Draw from e a line parallel to $b h$ to meet a vertical through h at f . This point is in the vertical plane of the end wall of the house, hence in the plane of $i h$. If now a 30° line be drawn from f parallel to $x b$, it will meet the roof of the house at g . The dormer ridge and $f g$ are in the same horizontal plane, hence will meet the roof at the same distance below the ridge $a i$. Therefore draw the 30° line $g c$, and connect c with d .

In Fig. 58 a box is shown with the cover opened through 150° .

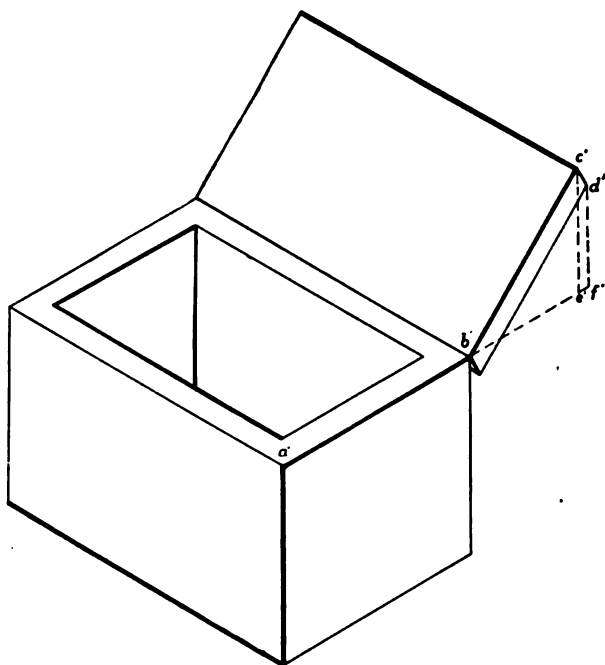


Fig. 58.

The right-hand edge of the bottom shows the width, the left-hand edge the length, and the vertical edge the height. The short edges of the cover are not isometric lines, hence are not shown in their true lengths; neither is the angle through which the cover is opened represented in its actual size.

The corners of the cover must then be determined by coordinates from an end view of the box and cover. As the end of the cover is in the same plane as the end of the box, the simple

end view as shown in Fig. 59 will be sufficient. Extend the top of the box to the right, and from c and d let fall perpendiculars or $a b$ produced, giving the points e and f . The point c may be located by means of the two distances or co-ordinates $b e$ and $e c$.

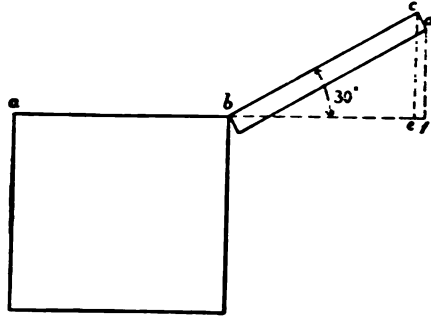


Fig. 59.

and these distances will appear in their true lengths in the isometric view. Hence produce $a' b'$ to e' and f' ; and from these points draw verticals $e' c'$ and $f' d'$; make $b' e'$ equal to $b e$, $e' c'$ equal to $e c$; and similarly for d' . Draw the lower edge parallel to $c' d'$ and equal to it in length, and connect with b' .

It will be seen that in isometric drawing parallel lines always appear parallel. It is also true that lines divided proportionally maintain this same relation in isometric drawing.

Fig. 60 shows a block or prism with a semicircular top. Find the isometric of the square circumscribing the circle, then draw the curve by the approximate method. The centers for the back face are found by projecting the front centers back 30° equal to the thickness of the prism, as shown at a and b .

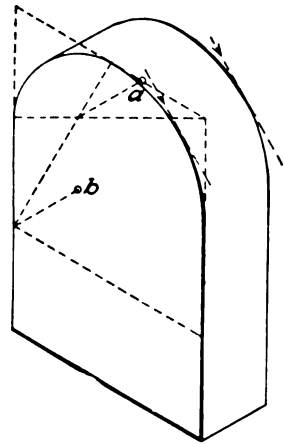


Fig. 60.

The plan and elevation of an oblique pentagonal pyramid are shown in Fig. 61. It is evident that none of the edges of the pyramid can be drawn in isometric as either vertical or 30° lines; hence, a system of co-ordinates must be used as

shown in Fig. 58. This problem illustrates the most general case; and to locate some of the points three co-ordinates must be used, two at 30° and one vertical.

Circumscribe, about the plan of the pyramid, a rectangle which shall have its sides respectively parallel and perpendicular to the ground line. This rectangle is on H, and its vertical projection is in the ground line.

The isometric of this rectangle can be drawn at once with 30° lines, as shown in Fig. 62, o being the same point in both figures

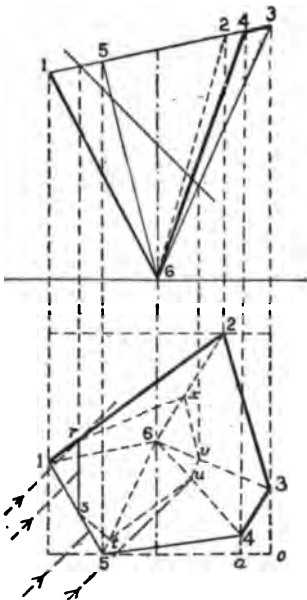


Fig. 61.

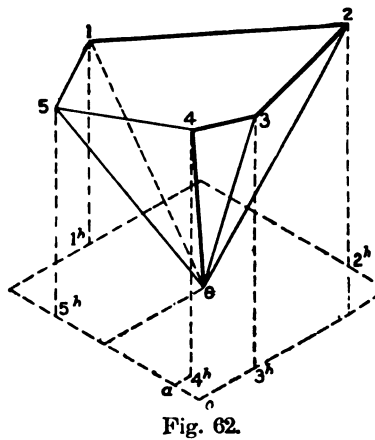


Fig. 62.

The horizontal projection of point 3 is found in isometric at 3^h , at the same distance from o as in the plan. That is, *any distance which in plan is parallel to a side of the circumscribing rectangle is shown in isometric in its true length and parallel to the corresponding side of the isometric rectangle*. If point 3 were on the horizontal plane its isometric would be 3^h , but the point is at the vertical height above H given in the elevation; hence, lay off above 3^h this vertical height, obtaining the actual isometric of the point. To locate 4, draw $4a$ parallel to the side of the rectangle; then lay

off $o a$ and $a 4^h$, giving what may be called the isometric plan of 4. Next, the vertical height taken from the elevation locates the isometric of the point in space.

In like manner all the corners of the pyramid, including the apex, are located. The rule is, *locate first in isometric the horizontal projection of a point by one or two 30° co-ordinates; then vertically, above this point, its height as taken from the elevation.* The shade lines cannot be determined here by applying the 30° or 60° triangle, owing to the obliquity of the faces. Since the right front corner of the

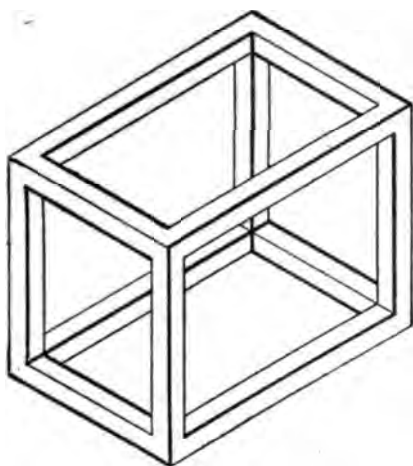


Fig. 63.

rectangle in plan was made the point o in isometric, the shade lines must be the same in isometric as in actual projection; so that,

if these can be determined in Fig. 61, they may be applied at once to Fig. 62.

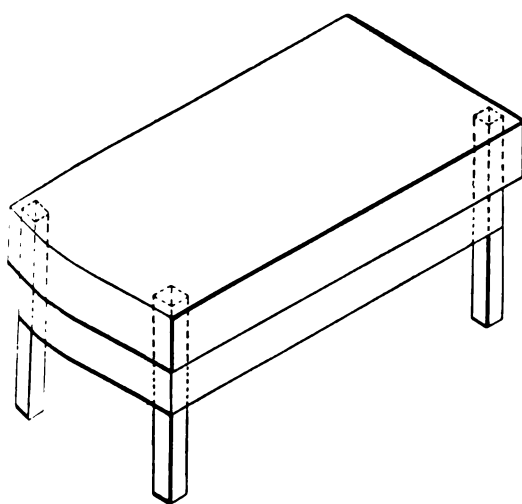


Fig. 64.

The shade lines in Fig. 61 are found by a short method which is convenient to use when the exact shade lines are desired, and when they cannot be determined by applying the 45° triangle. A plane is taken at 45° with the horizontal

plane, and parallel to the direction of the ray of light, in such a position as to cut all the surfaces of the pyramid, as shown in

elevation. This plane is perpendicular to the vertical plane; hence the section it cuts from the pyramid is readily found in plan by projection. This plane contains some of the rays of light falling upon the pyramid; and we can tell what surfaces these rays strike

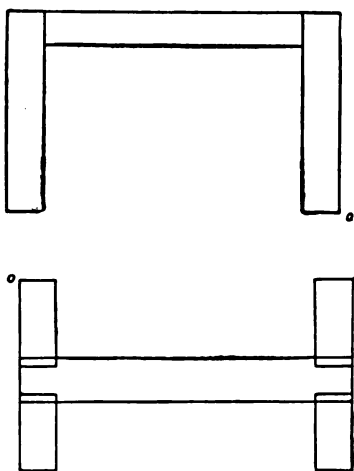


Fig. 65.

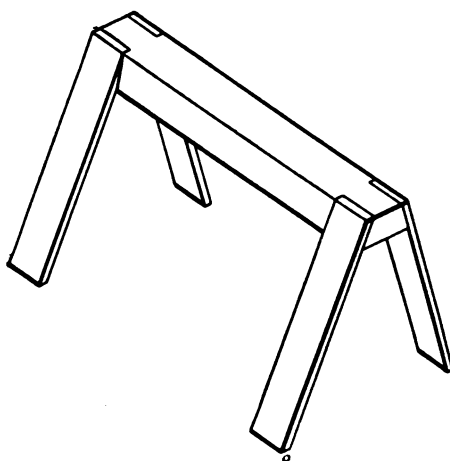


Fig. 66.

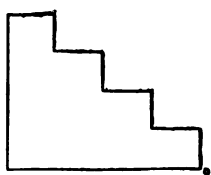


Fig. 67.

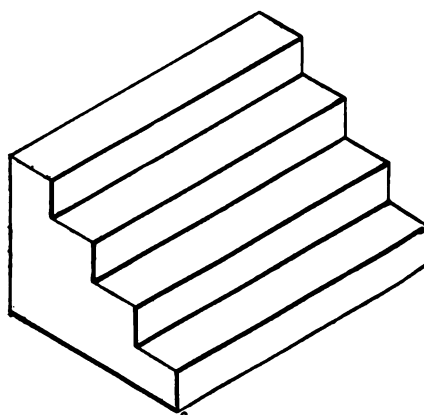


Fig. 68.

and make light, by noticing on the plan what edges of the section are struck by the projections of the rays of light. That is, rs , st , and tu receive the rays of light; hence the surfaces on which these lines lie are light. rs is on the surface determined by the two lines passing

through r and s , namely, $2-1$ and $1-5$; in other words, rs is on the base; similarly, st is on the surface $1-5-6$; and tu on the surface $4-6-5$. The other surfaces are dark; hence the edges which are between the light and dark faces are the shade lines.

Whenever it is more convenient, a plane parallel to the ray of light and perpendicular to H may be taken, the section found in elevation, and the 45° triangle applied to this section. The same method may be used to determine the exact shade lines of a cone or cylinder in an oblique position.

Figs. 63 to 70 give examples of the isometric of various objects. Fig. 65 is the plan and elevation, and Fig. 66 the

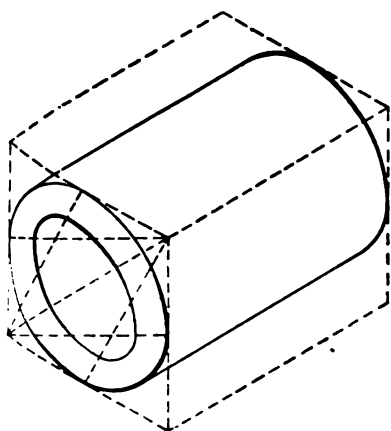


Fig. 69.

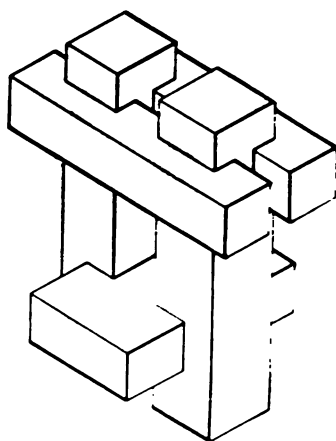


Fig. 70.

isometric, of a carpenter's bench. In Fig. 70, take especial notice of the shade lines. These are put on as if the group were made in one piece; and the shadows cast by the blocks on one another are disregarded. All upper horizontal faces are light, all left-hand (front and back) faces light, and the rest dark.

OBLIQUE PROJECTIONS.

In oblique projection, as in isometric, the end sought for is the same—a more or less complete representation, in one view, of any object. Oblique projection differs from isometric in that one face of the object is represented as if parallel to the vertical plane of projection, the others inclined to it. Another point of

difference is that oblique projection cannot be deduced from orthographic projection, as is isometric.

In oblique projection all lines in the front face are shown in their true lengths and in their true relation to one another, and lines which are perpendicular to this front face are shown in their true lengths at any angle that may be desired for any particular case. Lines not in the plane of the front face nor perpendicular

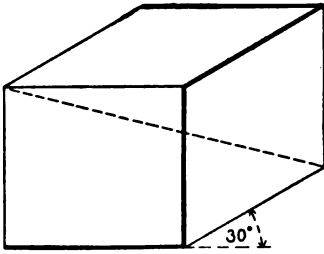


Fig. 71.

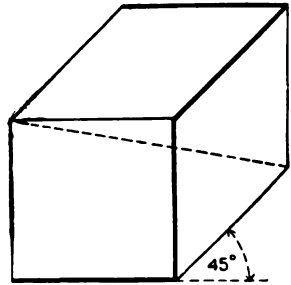


Fig. 72.

to it must be determined by co-ordinates, as in isometric. It will be seen at once that this system possesses some advantages over the isometric, as, for instance, in the representation of circles,

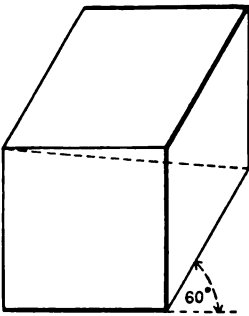


Fig. 73.

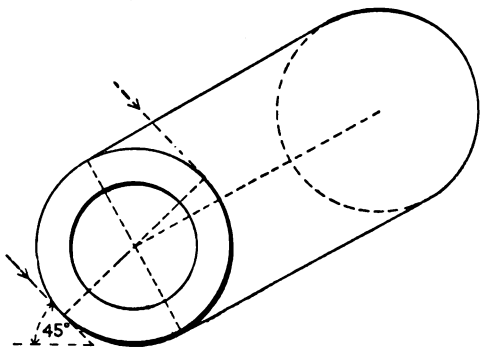


Fig. 74.

as any circle or curve in the front face is actually drawn as such.

The rays of light are still supposed to be parallel to the same diagonal of the cube, that is, sloping downward, toward the plane of projection, and to the right, or downward, backward and to the right. Figs. 71, 72 and 73 show a cube in oblique projection,

with the 30° , 45° and 60° slant respectively. The dotted diagonal represents for each case the direction of the light, and the shade lines follow from this.

The shade lines have the same general position as in isometric

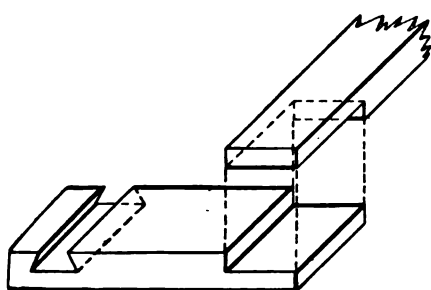


Fig. 75.

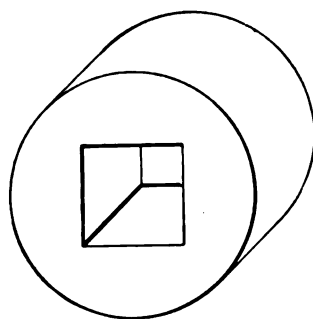


Fig. 76.

drawing, the top, front and left-hand faces being light. No matter what angle may be used for the edges that are perpendicular to the front face, the projection of the diagonal of the cube on this face is always a 45° line; hence, for determining the shade lines on

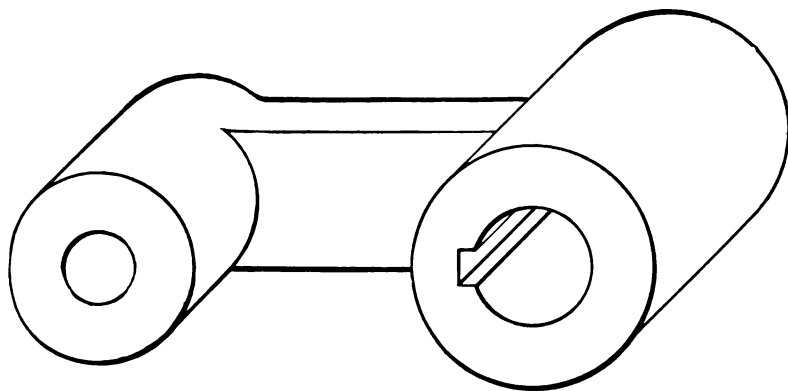


Fig. 77.

any front face, such as the end of the hollow cylinder in Fig. 74, the 45° line is used exactly as in the elevation of ordinary projections.

Figs. 75, 76, 77 and 79 are other examples of oblique projections. Fig. 77 is a crank arm.

The method of using co-ordinates for lines of which the true

lengths are not shown, is illustrated by Figs. 78 and 79. Fig. 79 represents the oblique projection of the two joists shown in plan and elevation in Fig. 78. The dotted lines in the elevation (see Fig. 78) show the heights of the corners above the horizontal stick. The feet of these perpendiculars give the horizontal distances of the top corners from the end of the horizontal piece.

In Fig. 79 lay off from the upper right-hand corner of the front end a distance equal to the distance between the front edge of the inclined piece and the front edge of the bottom piece (see Fig. 78). From this point draw a dotted line parallel to the

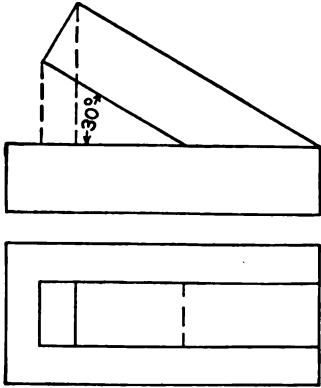


Fig. 78.

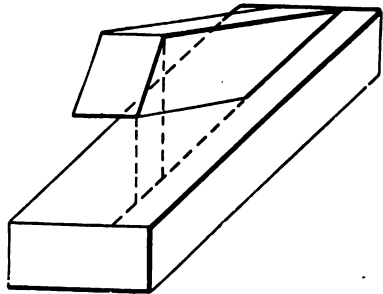


Fig. 79

length. The horizontal distances from the upper left corner to the dotted perpendicular are then marked off on this line. From these points verticals are drawn, and made equal in length to the dotted perpendiculars of Fig. 78, thus locating two corners of the end.

LINE SHADING.

In finely finished drawings it is frequently desirable to make the various parts more readily seen by showing the graduations of light and shade on the curved surfaces. This is especially true of such surfaces as cylinders, cones and spheres. The effect is obtained by drawing a series of parallel or converging lines on the surface at varying distances from one another. Sometimes draftsmen vary the width of the lines themselves. These lines are farther apart on the lighter portion of the surface, and are closer together and heavier on the darker part.

Fig. 80 shows a cylinder with elements drawn on the surface equally spaced, as on the plan. On account of the curvature of the surface the elements are not equally spaced on the elevation, but give the effect of graduation of light. The result is that in elevation the distances between the elements gradually lessen from the center toward each side, thus showing that the cylinder is convex. The effect is intensified, however, if the elements are made heavier, as well as closer together, as shown in Figs. 81 to 87.

Cylinders are often shaded with the light coming in the usual way, the darkest part commencing about where the shade line would actually be on the surface, and the lightest portion a little to the left of the center. Fig. 81 is a cylinder showing the heaviest shade at the right, as this method is often used. Considerable practice is necessary in order to obtain good results; but in this, as in other portions of mechanical drawing, perseverance has its reward. Fig. 82 represents a cylinder in a horizontal position, and Fig. 83 represents a section of a hollow vertical cylinder.



Fig. 80.



Fig. 81.

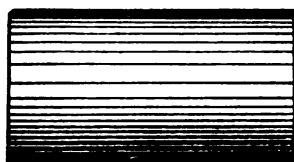


Fig. 82.

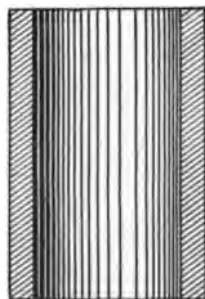


Fig. 83.

Figs. 84 to 87 give other examples of familiar objects.

In the elevation of the cone shown in Fig. 87 the shade lines should diminish in weight as they approach the apex. Unless this is done it will be difficult to avoid the formation of a blot at that point.

LETTERING.

All working drawings require more or less lettering, such as titles, dimensions, explanations, etc. In order that the drawing may appear finished, the lettering must be well done. No style of lettering should ever be used which is not perfectly legible. It is generally best to use plain, easily-made letters which present

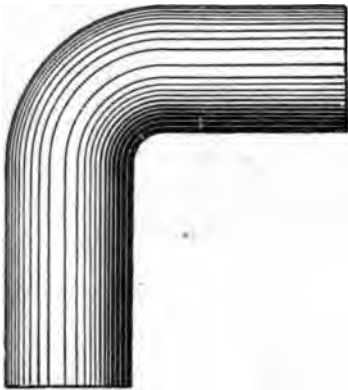


Fig. 84.

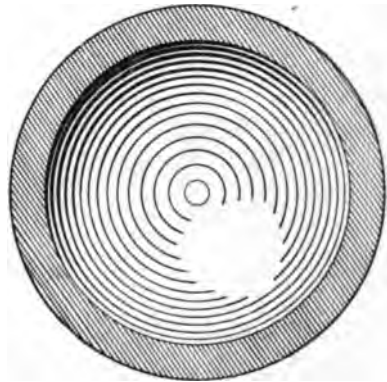


Fig. 85.



Fig. 86.

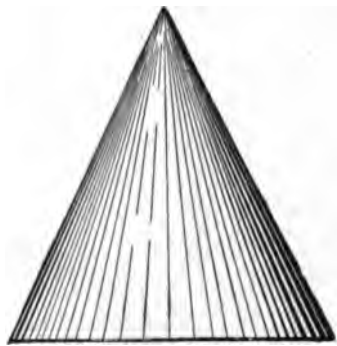


Fig. 87.

a neat appearance. Small letters used on the drawing for notes or directions should be made free-hand with an ordinary writing pen. Two horizontal guide lines should be used to limit the height of the letters; after a time, however, the upper guide line may be omitted.

In the early part of this course the inclined Gothic letter was described, and the alphabet given. The Roman, Gothic and block letters are perhaps the most used for titles. These letters, being of comparatively large size, are generally made mechanically; that is, drawing instruments are used in their construction. In order that the letters may appear of the same height, some of them, owing to their shape, must be made a little higher than the others. This is the case with the letters curved at the top and bottom, such as C, O, S, etc., as shown somewhat exaggerated in Fig. 88. Also, the letter A should extend a little above, and V a little below, the guide lines, because if made of the same height as the others they will appear shorter. This is true of all capitals, whether of Roman, Gothic, or other alphabets. In the block letter, however, they are frequently all of the same size.

There is no absolute size or proportion of letters, as the dimensions are regulated by the amount of space in which the letters are to be placed, the size of the drawing, the effect desired, etc. In some cases letters are made so that the height is greater than the width, and sometimes the reverse; sometimes the height and width are the same. This last proportion is the most common. Certain relations of width, however, should be observed. Thus, in whatever style of alphabet used, the W should be the widest letter; J the narrowest, M and T next widest to W, then A and B. The other letters are of about the same width.

In the vertical Gothic alphabet, the average height is that of B, D, E, F, etc., and the additional height of the curved letters and of the A and V is very slight. The horizontal cross lines of such letters as E, F, H, etc., are slightly above the center; those of A, G and P slightly below.

For the inclined letters, 60° is a convenient angle, although they may be at any other angle suited to the convenience or fancy of the draftsman. Many draftsmen use an angle of about 70° .

The letters of the Roman alphabet, whether vertical or inclined, are quite ornamental in effect if well made, the inclined Roman being a particularly attractive letter, although rather difficult to make. The block letter is made on the same general plan as the Gothic, but much heavier. Small squares are taken as



the unit of measurement, as shown. The use of this letter is not advocated for general work, although if made merely in outline the effect is pleasing. The styles of numbers corresponding with the alphabets of capitals given here, are also inserted. When a fraction, such as $2\frac{1}{2}$ is to be made, the proportion should be about as shown. For small letters, usually called lower-case letters,

abcdefghijklmnopqrstuvwxyz

Fig. 89.

abcdefghijklmnopqrstuvwxyz

Fig. 90.

abcdefghijklmnopqrstuvwxyz

Fig. 91.

the height may be made about two-thirds that of the capitals. This proportion, however, varies in special cases.

The principal lower-case letters in general use among draftsmen are shown in Figs. 89, 90, 91 and 92. The Gothic letters shown in Figs. 89 and 90 are much easier to make than the Roman letters in Figs. 91 and 92. These letters, however, do not

A B C D E F G H I J K L M N
 O P Q R S T U V W X Y Z
 1 2 3 4 5 6 7 8 9 0 & 2⁵₈

Vertical Roman Capitals.

A B C D E F G H I J K L M N
O P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0 & 2⁵₈

Inclined Roman Capitals.

give as finished an appearance as the Roman. As has already been stated in Mechanical Drawing, Part I, the inclined letter is easier to make because slight errors are not so apparent.

One of the most important points to be remembered in lettering is the spacing. If the letters are finely executed but poorly spaced, the effect is not good. To space letters correctly and rapidly, requires considerable experience; and rules are of little value on account of the many combinations in which letters are

abcdefghijklmnop
qrstuvwxyz

Fig. 92.

found. A few directions, however, may be found helpful. For instance, take the word TECHNICALITY, Fig. 93. If all the spaces were made equal, the space between the L and the I would appear to be too great, and the same would apply to the space between the I and the T. The space between the H and the N and that between the N and the I would be insufficient. In general, when the vertical side of one letter is followed by the vertical side of another, as in H E, H B, I R, etc., the maximum space

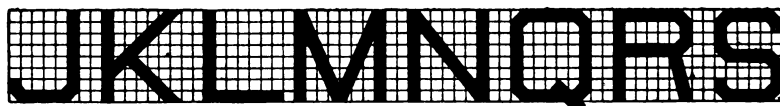
TECHNICALITY

Fig. 93.

should be allowed. Where T and A come together the least space is given, for in this case the top of the T frequently extends over the bottom of the A. In general, the spacing should be such that a uniform appearance is obtained. For the distances between words in a sentence, a space of about $1\frac{1}{2}$ the width of the average letter may be used. The space, however, depends largely upon the desired effect.

For large titles, such as those placed on charts, maps, and some large working drawings, the letters should be penciled before inking. If the height is made equal to the width considerable time and labor will be saved in laying out the work. This is especially true with such Gothic letters as O, Q, C, etc., as these letters may then be made with compasses. If the letters are of sufficient size, the outlines may be drawn with the ruling pen or compasses, and the spaces between filled in with a fine brush.

The titles for working drawings are generally placed in the lower right-hand corner. Usually a draftsman has his choice of

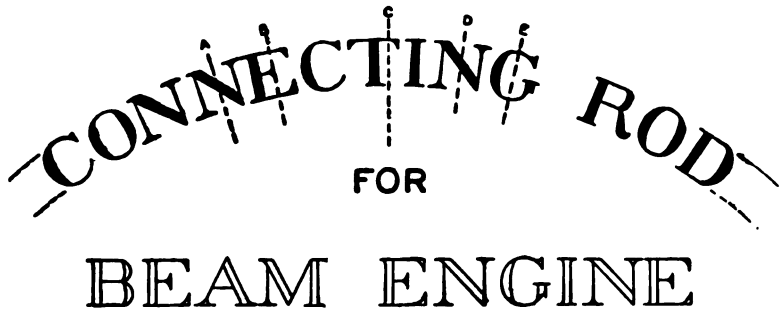


Block Letters.

letters, mainly because after he has become used to making one style he can do it rapidly and accurately. However, in some drafting rooms the head draftsman decides what lettering shall be used. In making these titles, the different alphabets are selected to give the best results without spending too much time. In most work the letters are made in straight lines, although we frequently find a portion of the title lettered on an arc of a circle.

In Fig. 94 is shown a title having the words CONNECTING ROD lettered on an arc of a circle. To do this work requires considerable patience and practice. First draw the vertical center

line as shown at C in Fig. 94. Then draw horizontal lines for the horizontal letters. The radii of the arcs depend upon the general arrangement of the entire title, and this is a matter of taste. The difference between the arcs should equal the height of the letters. After the arc is drawn, the letters should be sketched in pencil to find their approximate positions. After this is done, draw radial lines from the center of the letters to the center of the arcs.



SCALE 3 INCHES = 1 FOOT

PORTLAND COMPANY'S WORKS

JULY 10, 1894

Fig. 94.

These lines will be the centers of the letters, as shown at A, B, D and E. The vertical lines of the letters should not radiate from the center of the arc, but should be parallel to the center lines already drawn; otherwise the letters will appear distorted. Thus, in the letter N the two verticals are parallel to the line A. The same applies to the other letters in the alphabet.

PLATES.**PLATE IX.**

The plates of this Instruction Paper should be laid out at the same size as the plates in Parts I and II. The center lines and border lines should also be drawn as described.

First draw two ground lines across the sheet, 3 inches below the upper border line and 3 inches above the lower border line. The first problem on each ground line is to be placed 1 inch from the left border line; and spaces of about 1 inch should be left between the figures.

Isolated points are indicated by a small cross X, and projections of lines are to be drawn full unless invisible. All construction lines should be fine dotted lines. Given and required lines should be drawn full.

Problems on Upper Ground Line :

1. Locate both projections of a point on the horizontal plane 1 inch from the vertical plane.

2. Draw the projections of a line 2 inches long which is parallel to the vertical plane and which makes an angle of 45 degrees with the horizontal plane and slants upward to the right.

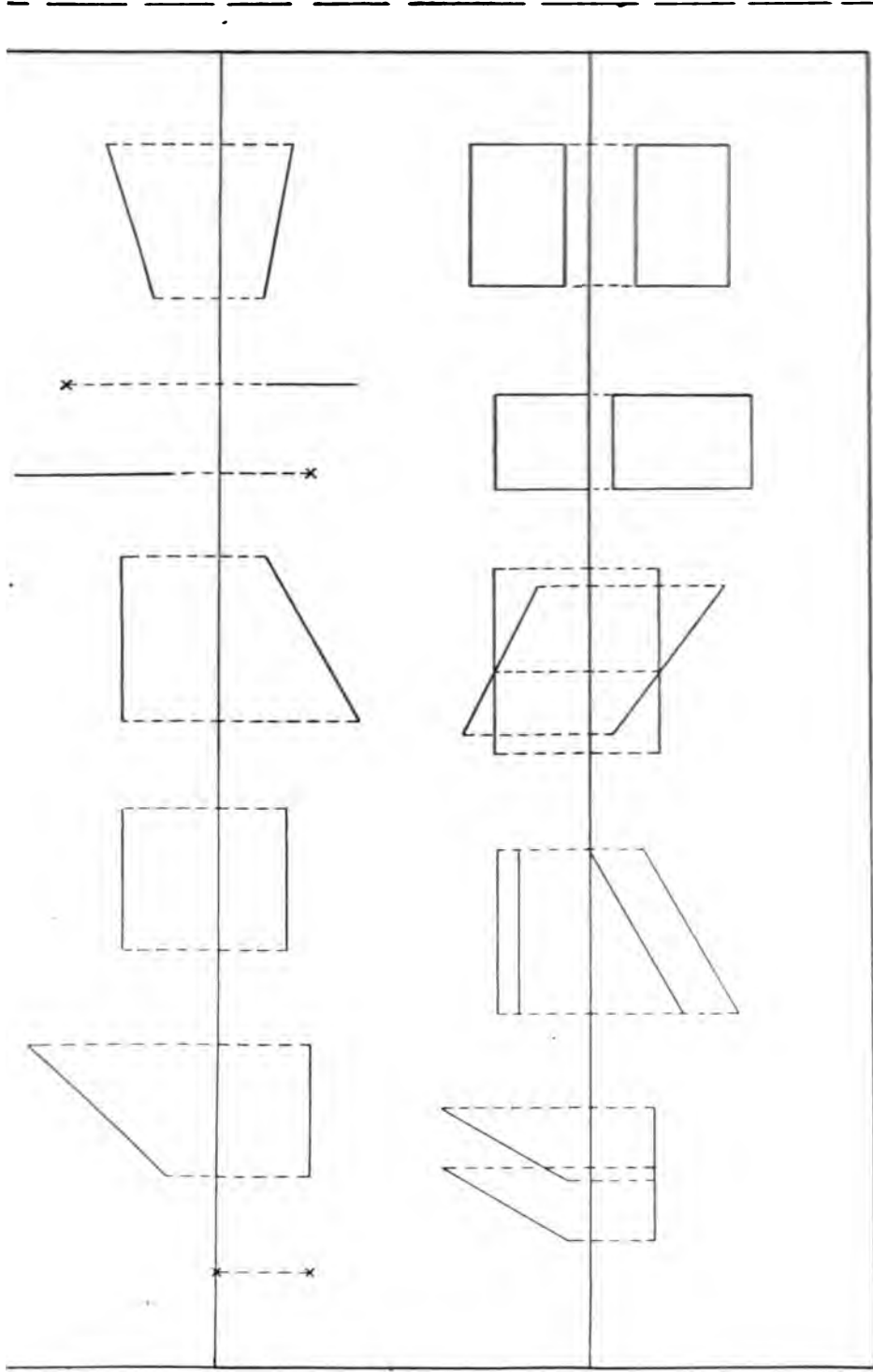
The line should be 1 inch from the vertical plane and the lower end $\frac{1}{2}$ inch above the horizontal.

3. Draw the projections of a line $1\frac{1}{2}$ inches long which is parallel to both planes, 1 inch above the horizontal, and $\frac{3}{4}$ inch from the vertical.

4. Draw the plan and elevation of a line 2 inches long which is parallel to H and makes an angle of 30 degrees with V. Let the right-hand end of the line be the end nearer V, $\frac{1}{2}$ inch from V. The line to be 1 inch above H.

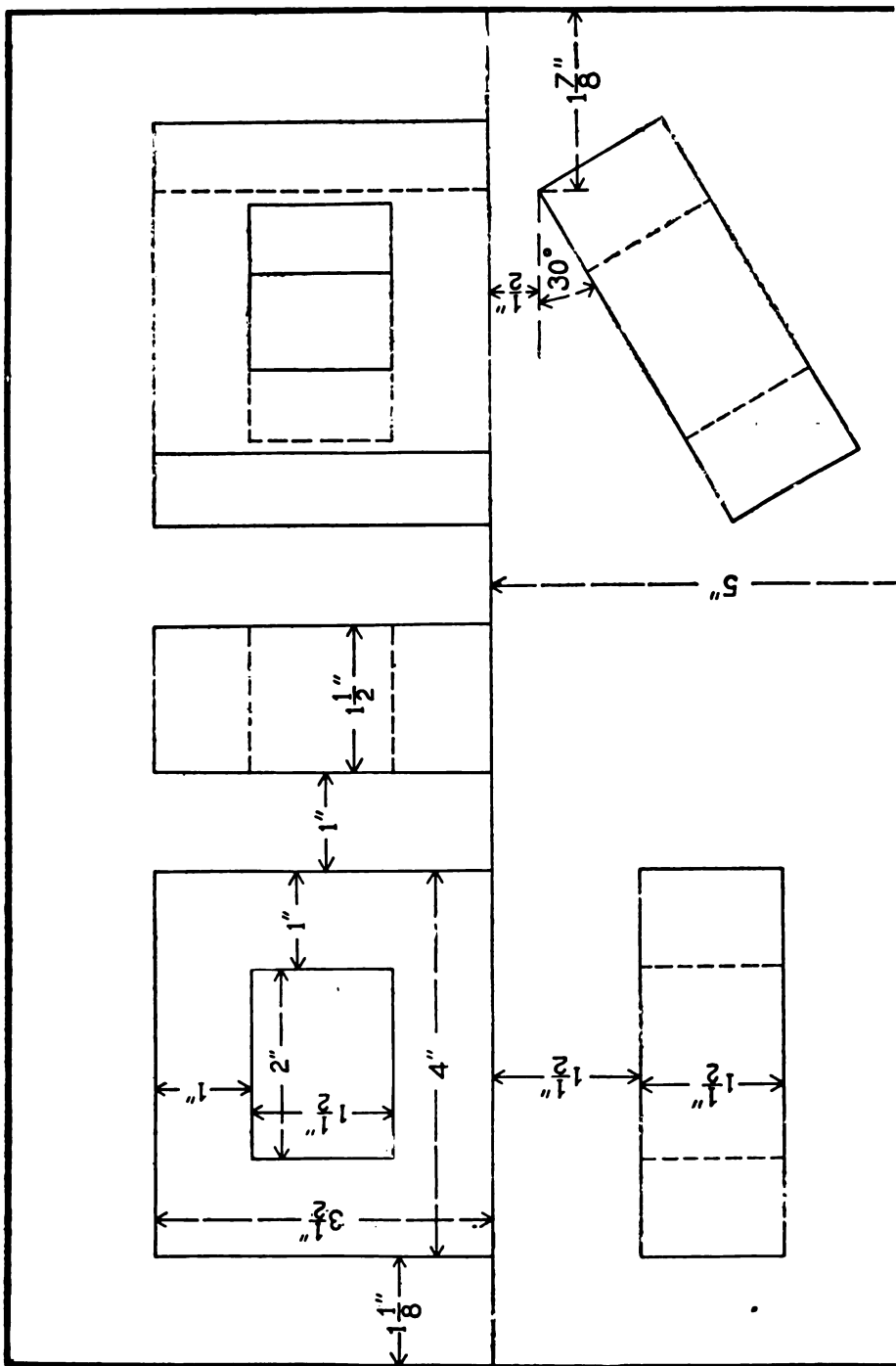
5. Draw the plan and elevation of a line $1\frac{1}{2}$ inches long which is perpendicular to the horizontal plane and 1 inch from the vertical. Lower end of line is $\frac{1}{2}$ inch above H.

6. Draw the projections of a line 1 inch long which is perpendicular to the vertical plane and $1\frac{1}{2}$ inches above the horizontal. The end of the line nearer V, or the back end, is $\frac{1}{2}$ inch from V.



HERBERT CHANDLER, CHICAGO, ILL.

FEBRUARY 17, 1901.



7. Draw two projections which shall represent a line oblique to both planes.

NOTE. Leave 1 inch between this figure and the right-hand border line.

Problems on Lower Ground Line:

8. Draw the projections of two parallel lines each $1\frac{1}{2}$ inches long. The lines are to be parallel to the vertical plane and to make angles of 60 degrees with the horizontal. The lower end of each line is $\frac{1}{4}$ inch above H. The right-hand end of the right-hand line is to be $2\frac{3}{4}$ inches from the left-hand margin.

9. Draw the projections of two parallel lines each 2 inches long. Both lines to be parallel to the horizontal and to make an angle of 30 degrees with the vertical. The lower line to be $\frac{3}{4}$ inch above H, and one end of one line to be against V.

10. Draw the projections of two intersecting lines. One 2 inches long to be parallel to both planes, 1 inch above H, and $\frac{3}{4}$ inch from the vertical; and the other to be oblique to both planes and of any desired length.

11. Draw plan and elevation of a prism 1 inch square and $1\frac{1}{2}$ inches long. The prism to have one side on the horizontal plane, and its long edges to be perpendicular to V. The back end of the prism is $\frac{1}{4}$ inch from the vertical plane.

12. Draw plan and elevation of a prism the same size as given above, but with the long edges parallel to both planes, the lower face of the prism to be parallel to H and $\frac{1}{4}$ inch above it. The back face to be $\frac{1}{2}$ inch from V.

PLATE X.

The ground line is to be in the middle of the sheet, and the location and dimensions of the figures are to be as given. The first figure shows a rectangular block with a rectangular hole cut through from front to back. The other two figures represent the same block in different positions. The second figure is the end or profile projection of the block. The same face is on H in all three positions. Be careful not to omit the shade lines. The figures given on the plate for dimensions, etc., are to be used but not repeated on the plate by the student.

PLATE XI.

Three ground lines are to be used on this plate, two at the left $4\frac{1}{2}$ inches long and 3 inches from top and bottom margin lines; and one at the right, half way between the top and bottom margins, $9\frac{1}{2}$ inches long.

The figures 1, 2, 3 and 4 are examples for finding the true lengths of the lines. Begin No. 1 $\frac{3}{4}$ inch from the border, the vertical projection $1\frac{3}{4}$ inches long, one end on the ground line and inclined at 30° . The horizontal projection has one end $\frac{1}{2}$ inch from V, and the other $1\frac{1}{2}$ inches from V. Find the true length of the line by completing the construction commenced by swinging the arc, as shown in the figure.

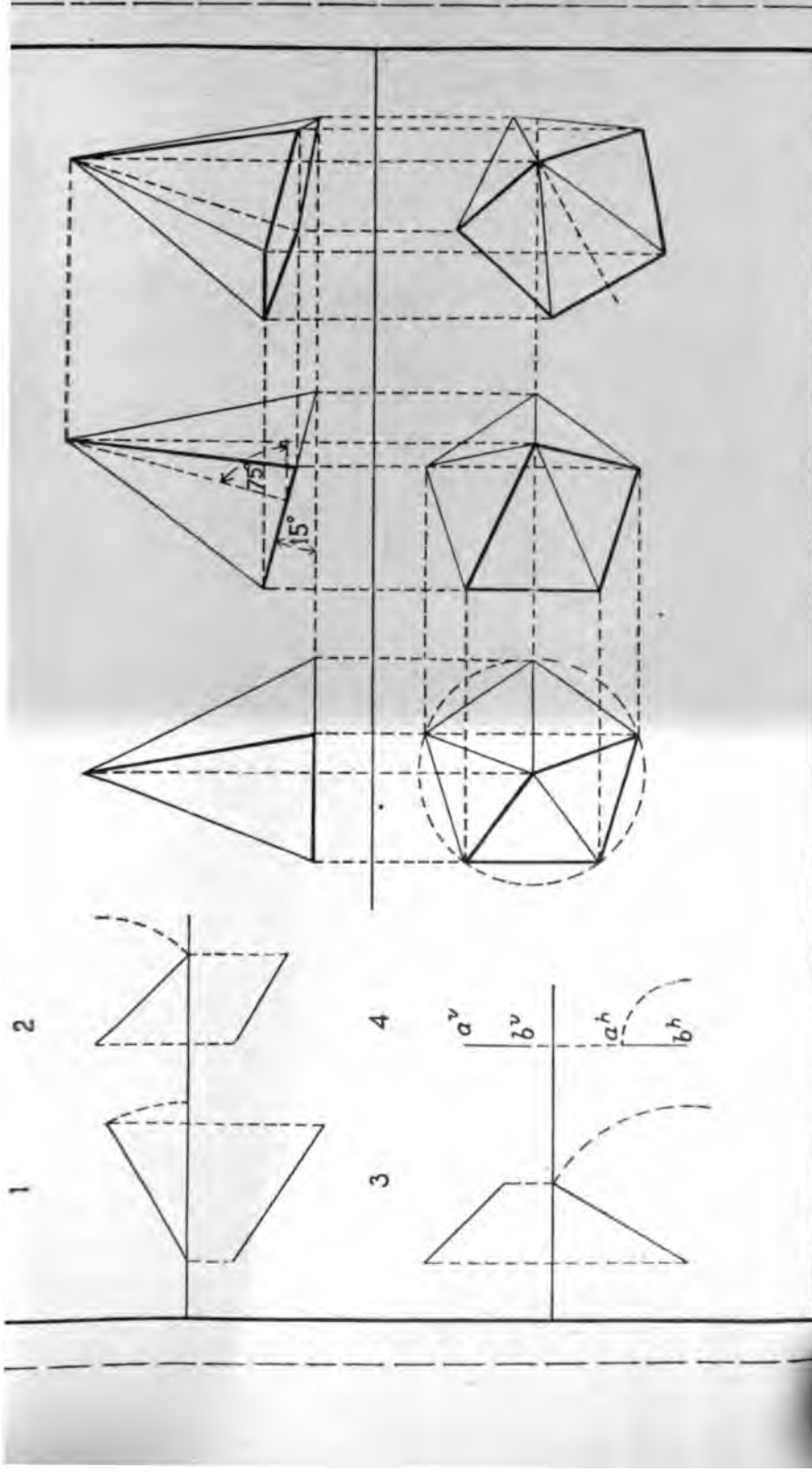
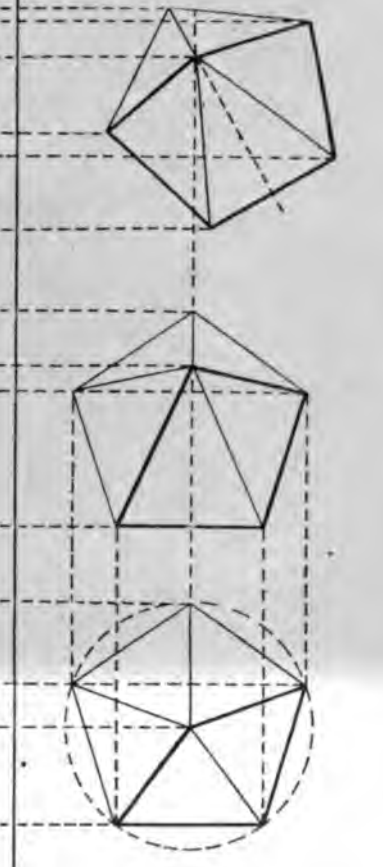
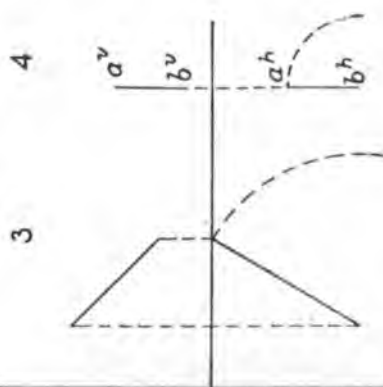
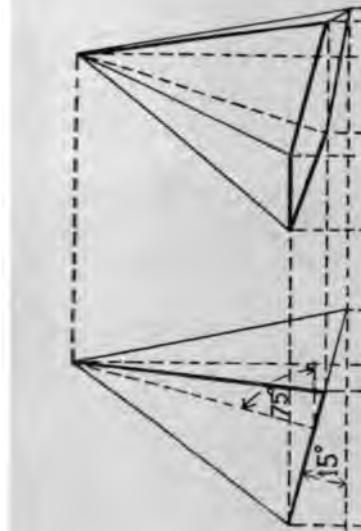
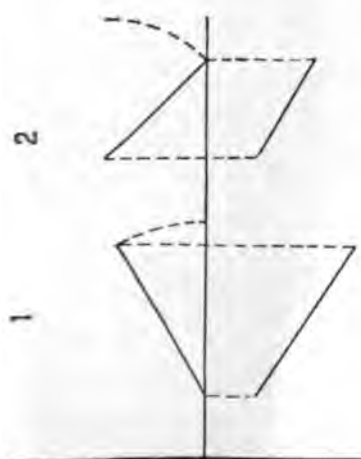
Locate the left-hand end of No. 2 3 inches from the border, 1 inch above H, and $\frac{5}{8}$ inch from V. Extend the vertical projection to the ground line at an angle of 45° , and make the horizontal projection at 30° . Complete the construction for true length as commenced in the figure.

In Figs. 3 and 4, the true lengths are to be found by completing the revolutions indicated. The left-hand end of Fig. 3 is $\frac{3}{4}$ inch from the margin, $1\frac{1}{2}$ inches from V, and $1\frac{3}{8}$ inches above H. The horizontal projection makes an angle of 60° and extends to the ground line, and the vertical projection is inclined at 45° .

The fourth figure is 3 inches from the border, and represents a line in a profile plane connecting points *a* and *b*. *a* is $1\frac{1}{4}$ inches above H and $\frac{3}{4}$ inch from V; and *b* is $\frac{1}{4}$ inch above H and $1\frac{1}{2}$ inches from V.

The figures for the middle ground line represent a pentagonal pyramid in three positions. The first position is the pyramid with the axis vertical, and the base $\frac{5}{8}$ inch above the horizontal. The height of the pyramid is $2\frac{1}{2}$ inches, and the diameter of the circle circumscribed about the base is $2\frac{1}{2}$ inches. The center of the circle is 6 inches from the left margin and $1\frac{3}{4}$ inches from V. Spaces between figures to be $\frac{3}{4}$ inch.

In the second figure the pyramid has been revolved about the right-hand corner of the base as an axis, through an angle of 15° . The axis of the pyramid, shown dotted, is therefore at 75° . The method of obtaining 75° and 15° with the triangles was shown in



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Part I. From the way in which the pyramid has been revolved, all angles with V must remain the same as in the first position; hence the vertical projection will be the same shape and size as before. All points of the pyramid remain the same distance from V. The points on the plan are found on T-square lines through the corners of the first plan and directly beneath the points in elevation. In the third position the pyramid has been swung around, about a vertical line through the apex as axis, through 30° . The angle with the horizontal plane remains the same; consequently the plan is the same size and shape as in the

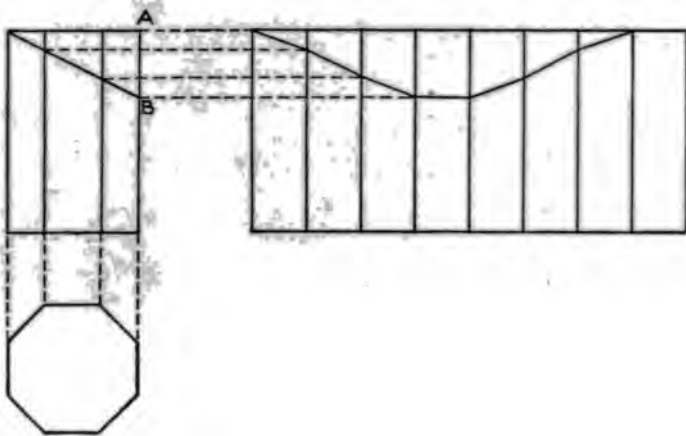


Fig. 96.

second position, but at a different angle with the ground line. Heights of all points of the pyramid have not changed this time, and hence are projected across from the second elevation. Shade lines are to be put on between the light and dark surfaces as determined by the 45° triangle.

PLATE XII.

Developments.

On this plate draw the developments of a truncated octagonal prism, and of a truncated pyramid having a square base. The arrangement on the plate is left to the student; but we should suggest that the truncated prism and its development be placed at

the left, and that the development of the truncated pyramid be placed under the development of the prism; the truncated pyramid may be placed at the right.

The prism and its development are shown in Fig. 96. The prism is 3 inches high, and the base is inscribed in a circle $2\frac{1}{2}$ inches in diameter. The plane forming the truncated prism is passed as indicated, the distance A B being 1 inch. Ink a sufficient number of construction lines to show clearly the method of finding the development.

The pyramid and its development are shown in Fig. 97. Each side of the square base is 2 inches, and the altitude is $3\frac{1}{2}$ inches.

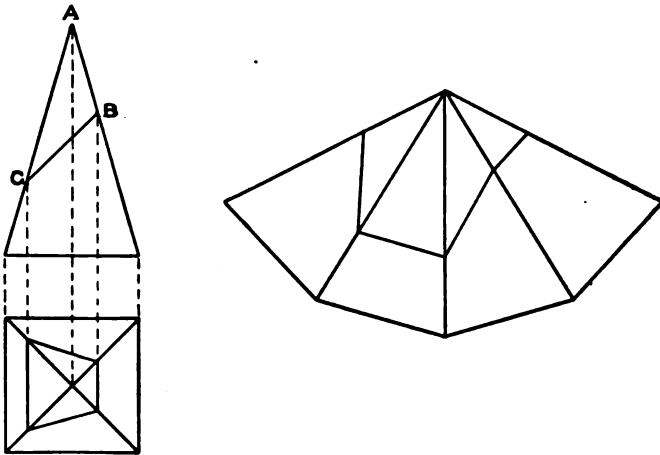


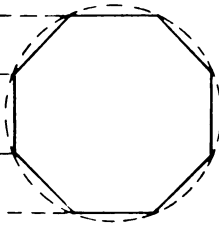
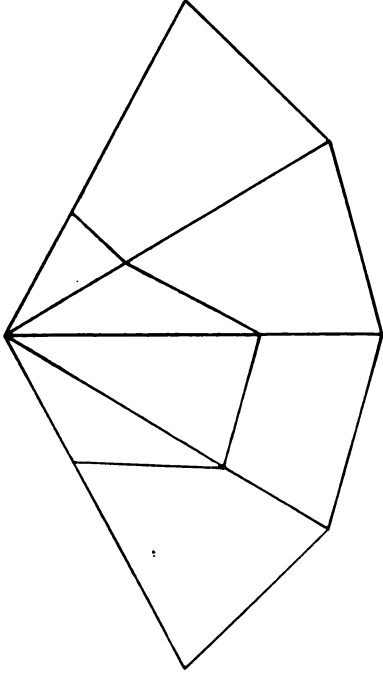
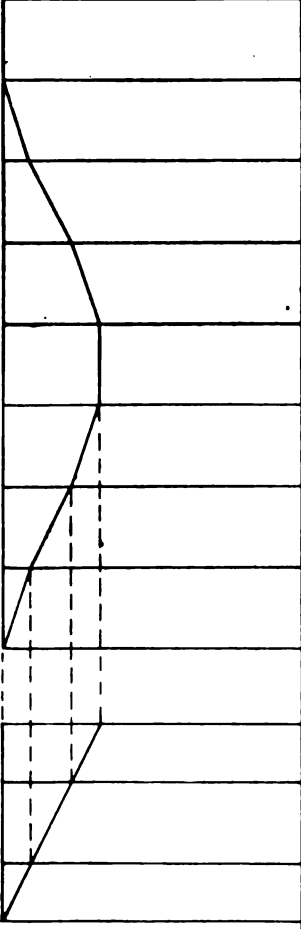
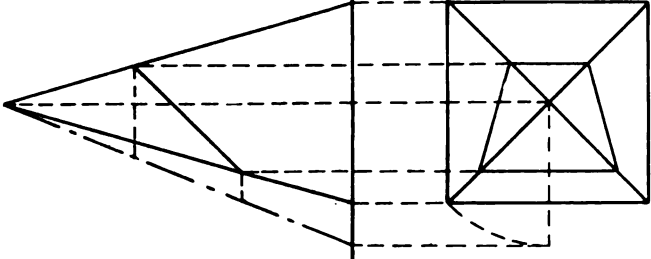
Fig. 97.

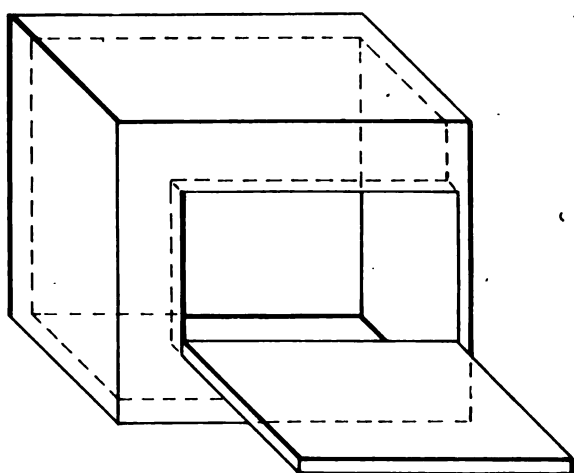
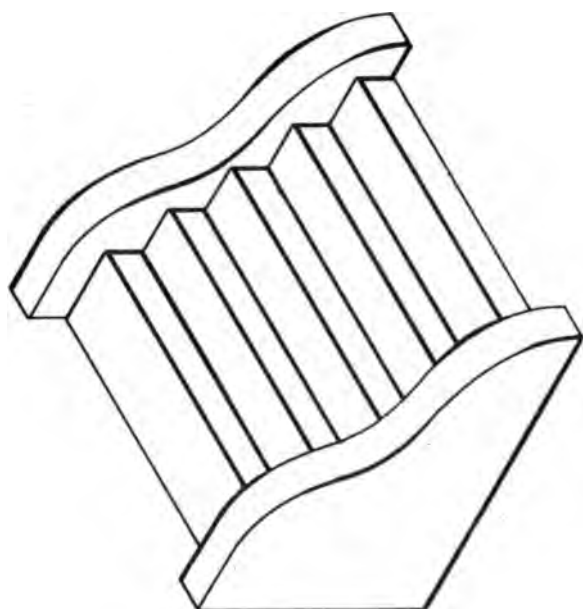
The plane forming the truncated pyramid is passed in such a position that A B equals $1\frac{3}{4}$ inches, and A C equals $2\frac{1}{2}$ inches. In this figure the development may be drawn in any convenient position, but in the case of the prism it is better to draw the development as shown. Indicate clearly the construction by inking the construction lines.

PLATE XIII.

Isometric and Oblique Projection.

Draw the oblique projection of a portable closet. The angle to be used is 45° . Make the height $3\frac{1}{2}$ inches, the depth $1\frac{1}{2}$ inches, and the width 3 inches. See Fig. 98. The width of the closet





is to be shown as the left-hand face. The front left-hand lower corner is to be 1 inch from the left-hand border line and 2 inches from the lower border line. The door to be placed in the closet should be $1\frac{5}{8}$ inches wide and $2\frac{3}{4}$ inches high. Place the door

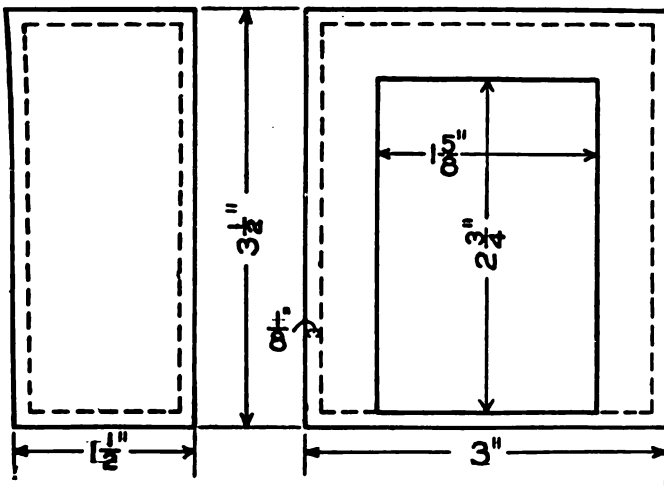


Fig. 98.

centrally in the front of the closet, the bottom edge at the height of the floor of the closet, the hinges of the door to be placed on the left-hand side. In the oblique drawing, show the door opened at an angle of 90 degrees. The thickness of the material of the closet, door, and floor is $\frac{1}{8}$ inch. The door should be hung so that when closed it will be flush with the front of the closet.

Make the isometric drawing of the flight of steps and end walls as shown by the end view in Fig. 99. The lower right-hand corner is to be located $2\frac{1}{4}$ inches from the lower, and 5 inches from the right-hand, margin. The base of the end wall is $3\frac{1}{8}$ inches long, and the height is $2\frac{1}{4}$ inches. Beginning from the back of the wall, the top is horizontal for $\frac{5}{8}$ inch, the remainder of the outline being composed of arcs of circles whose radii and centers are given

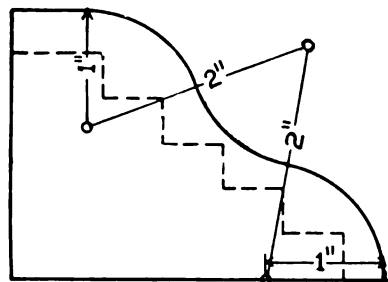


Fig. 99.

in the figure. The thickness of the end wall is $\frac{3}{8}$ inch, and both ends are alike. There are to be five steps; each rise is to be $\frac{3}{8}$ inch, and each tread $\frac{1}{2}$ inch, except that of the top step, which is $\frac{3}{4}$ inch. The first step is located $\frac{3}{8}$ inch back from the corner of the wall. The end view of the wall should be constructed on a separate sheet of paper, from the dimensions given, the points on the curve being located by horizontal co-ordinates from the vertical edge of the wall, and then these co-ordinates transferred to the isometric drawing. After the isometric of one curved edge has been made, the others can be readily found from this. The width of the steps inside the walls is 3 inches.

PLATE XIV.

Free-hand Lettering.

On account of the importance of free-hand lettering, the student should practice it at every opportunity. For additional practice, and to show the improvement made since completing Part I, lay out Plate XIV in the same manner as Plate I, and letter all four rectangles. Use the same letters and words as in the lower light-hand rectangle of Plate I.

PLATE XV.

Lettering.

First lay out Plate XV in the same manner as previous plates. After drawing the vertical center line, draw light pencil lines as guide lines for the letters. The height of each line of letters is shown on the reproduced plate. The distance between the letters should be $\frac{1}{2}$ inch in every case. The spacing of the letters is left to the student. He may facilitate his work by lettering the words on a separate piece of paper, and finding the center by measurement or by doubling the paper into two equal parts. The styles of letters shown on the reproduced plate should be used.

COURSE
IN
MECHANICAL DRAWING
AMERICAN SCHOOL
OF
CORRESPONDENCE
CHICAGO, ILL., U.S.A.
1901

ASSEMBLY AND DETAILS

BODY
BRASS CASTING : ONE



MECHANICAL DRAWING.

WORKING DRAWINGS.

In Mechanical Drawing Parts I, II and III, instruments and materials are described and some hints given regarding the use of compasses, line pen, triangles, T-square, etc. In addition, the general principles upon which all Mechanical Drawing depends, are explained. After completing this work the student should be able to draw neatly and accurately and apply the fundamental principles.

Let us now take up the subject of working drawings and see how the principles of orthographic projection are made of practical use. We shall see, as we go on, that to a great extent the theoretical principles already learned in the study of projections are used in practical working shop drawings. Nevertheless, there are certain instances in which actual practice differs slightly from the theory.

We shall also find that all draftsmen do not follow the same customs in the matter of minor details, but that in many cases there are several ways of representing objects, all of which may be equally correct, one draftsman using one method either because he prefers it or because it best serves the purpose for which his particular work is being done, while another draftsman uses a different method. The more important principles and customs, however, are pretty well established.

A study of the subject of working drawings should, first, teach us the methods of the best drafting rooms; second, should train our judgment to decide how best to represent the particular object which we have to draw; third, should train our hand and eye to make a clear, neat and well-executed drawing, without unnecessary expenditure of time.

Definition of Working Drawing. A working drawing of any object is a drawing which completely describes the object in every particular, showing its form, size, material, finish, and all other details, so that a workman may take the drawing and without any further instructions make the object exactly as the draftsman intended it to be made. The drawing is, therefore, a sort of language, by which the man who designs the object describes it to the

planes which intersect at right angles, the planes and the object being supposed to be in the position represented in Fig. 3, the

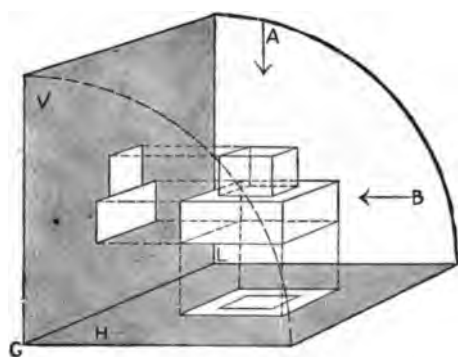


Fig. 3.

horizontal plane H being below the object, and the vertical plane V being beside the object. We then projected down to the horizontal plane and represented there the object as it would appear if seen squarely in the direction indicated by arrow A. We next projected into the vertical plane, and represented the object as it

would appear if the line of vision took the direction of the arrow B. Our planes, with the horizontal and vertical projections of the object on them, when laid out flat, as a sheet of paper is when actually drawn on it, would appear as in Fig. 4, the horizontal projection, or top view, being *underneath* the vertical projection, or side view. This is the practice followed by some draftsmen in making working drawings. Many of the best draftsmen, however, think that it is not as clear and convenient to have the top view of the object underneath the side view, but that it is better to have the view of the top above the other view. Consequently, it is becoming more and more a general custom to suppose the planes to be transparent and to be located with respect to the piece which is being drawn as shown in Fig. 5, the H plane being above the object and the V plane in front of the object. They then draw on the H plane the object as it appears when looking at it

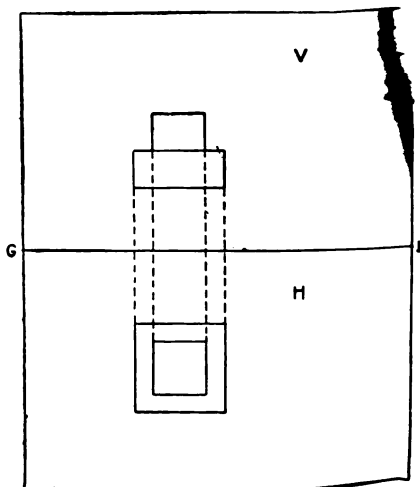


Fig. 4.

is being drawn as shown in Fig. 5, the H plane being above the object and the V plane in front of the object. They then draw on the H plane the object as it appears when looking at it

through the transparent plane in the direction indicated by arrow C, and on the V plane the object as it appears when looking in direction of arrow D. Now, when the two planes are laid out flat, the top view is above the side view, as in Fig. 6.

Another way of showing this is to suppose the object to be located in a transparent box, and that we look at it from the top and the various sides of the box, and draw on these sides the object as it appears from that side. Then, if the sides of the box are laid out flat, the side view

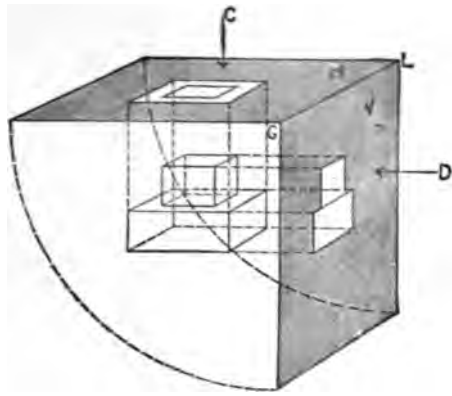


Fig. 5.

will come in the middle, with the top view above, the view of the bottom underneath, the view of the right-hand side on the right, and the view of the left-hand side on the left.

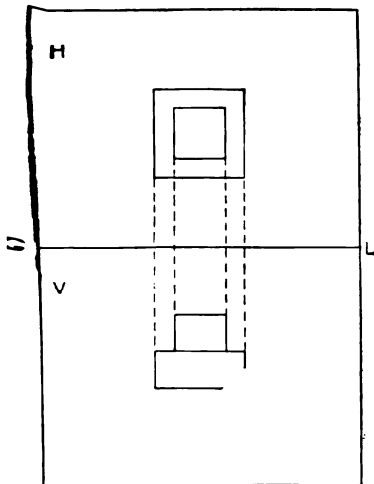


Fig. 6.

From now on, in our work on drawing, we shall follow this rule.

Cross-sections. Very often it occurs that a piece is hollow and the inside construction is more or less complicated, so that if in the drawing the outside view is shown, with the invisible interior drawn in dotted lines, the latter are so confused that the drawing is not easily understood. For this reason it is often convenient to imagine the piece to be cut open, and to

draw it as if we were looking directly at the inside. Such a drawing of a piece is called a cross-section of the piece. The material which must be cut if the object were actually split open is then crosshatched, different kinds of crosshatching being

used for different materials. Fig. 7 shows the kinds of cross-hatching in ordinary use.

Fig. 8 shows a plan and elevation of a simple piece with a hole through it, the hole being shown in the elevation by dotted lines. Fig. 9 shows a plan and a cross-section of the same piece, the cross-section being drawn as if we were looking in the same direction as in the elevation of Fig. 8, but in Fig. 9 the front half is supposed to be cut away and we are looking at the inside of the back half. It will be observed that even on a piece as

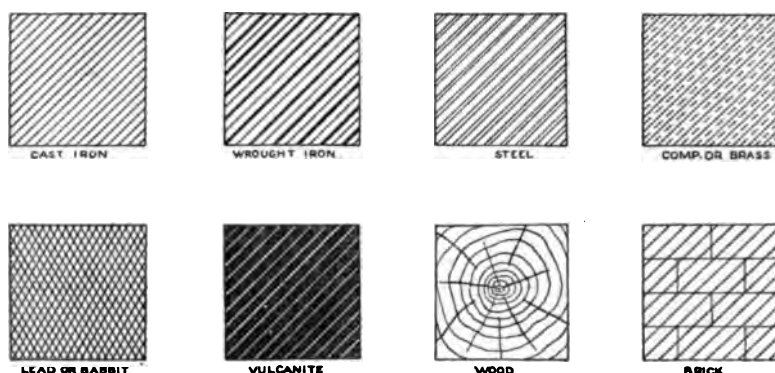


Fig. 7.

simple as the one here shown, the shape of the interior is much clearer from the cross-section than from the elevation, and on a more complicated piece the same will be true to a greater extent.

It should be borne in mind that ordinarily in making a cross-section we show not only those parts of the object which lie in the plane in which it is supposed to be cut, but also all which lie back of that plane.

Sometimes it is desirable to show the inside and the outside of a piece on the same view. Fig. 10 shows the same piece as in Fig. 8, but in Fig. 10 the left-hand half of the lower view is an elevation and the right-hand half is a cross-section, the section and the elevation each extending to the center and being separated by a center line. This is as if one-quarter of it were cut away, the cuts being made along the lines C A and C B of the plan view.

Of course this combination of an elevation and cross-section

can be used only when the right-hand and left-hand halves of the piece are alike.

Shade Lines. In order to make drawings easier to read, and to make the parts of the object stand out more clearly, shade lines are often put on the drawing. The general principle which determines what lines shall be shade lines is the same as that which governs shade lines already studied under the subject of projections. If, however, this theoretical principle were to be followed out exactly on drawings of machines, and other complicated drawings, it would involve a great deal of time and labor.

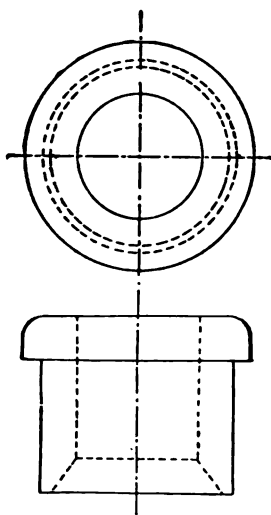


Fig. 8.

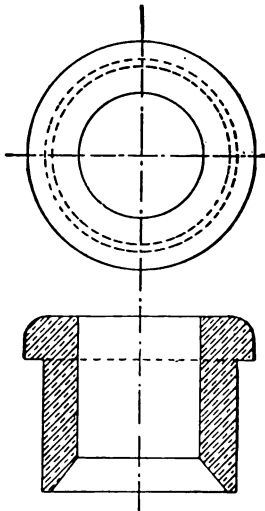


Fig. 9.

Consequently, most draftsmen place shade lines on all lines which represent lower and right-hand edges if these edges are sharp.

The contour lines of cylinders, cones and other rounded surfaces should not be shade lines, although some draftsmen shade them. If the cylinder is drawn in cross-section, however, the edge should be shaded, as the intersection of the plane and cylindrical surface is a sharp edge.

All views are shaded alike, and both are shaded as though they were elevations. The ray of light is supposed to come over

the left shoulder of the draftsman, as he faces the paper, at such an angle that the projection of the ray of light on the drawing paper is in the direction of the arrow in Fig. 11.

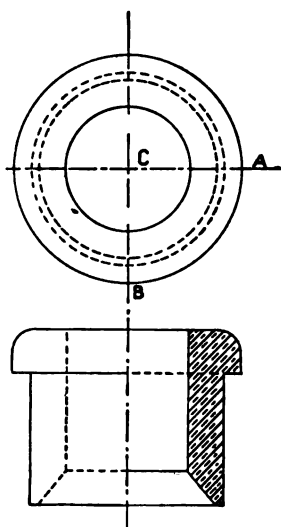


Fig. 10.

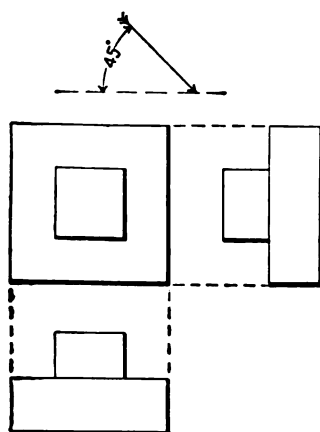


Fig. 11.

Figs. 11 to 18 show some of the most common shapes met with in drawings, and illustrate how the shade lines are placed on each. Fig. 11 is an elevation, plan, and side view of a rectangular

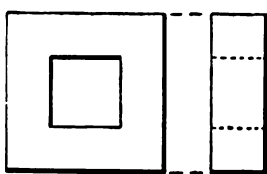


Fig. 12.

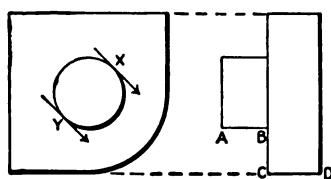


Fig. 13.

prism with a smaller one resting on top of it. Fig. 12 is a plan and side view of a rectangular prism with a rectangular hole through it. It is to be noticed that the shade lines come on the upper and left-hand sides of the hole, since these lines are the

lower and right-hand edges of the material which surrounds the hole. Fig. 13 is a plan and side view of a rectangular prism with one corner rounded, and with a cylinder resting on it. Here the lines A B and C D are not shaded, since they are the contour lines of curved surfaces. In the plan view, the lower right-hand part of the circle, between X and Y, is shaded. To find these points X and Y, draw two lines tangent to the circle and making an angle of 45° with the T-square line as shown by the arrows; X and Y are the points where the arrows are tangent to the circle. Fig. 14 is a plan, elevation and cross-section of a cylinder.

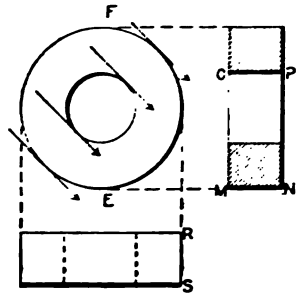


Fig. 14.

Here, in the plan, the larger circle is shaded on the lower side, and the circle which represents the hole is shaded on the upper side. The points where the shade begins are determined as explained for Fig. 13. The lines M N and O P are shaded since,

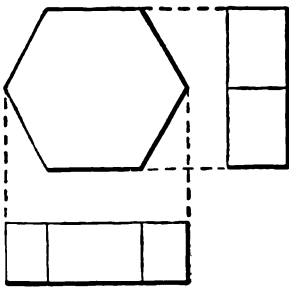


Fig. 15.

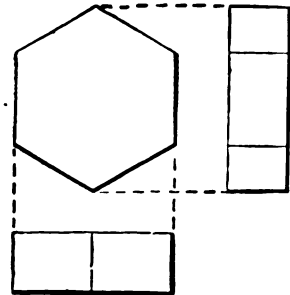


Fig. 16.

as the cylinder is supposed to be cut open, these lines now represent sharp edges. Fig. 15 is a plan, elevation and side view of a hexagonal prism with its long diameter parallel to the bottom of the paper. Fig. 16 is the same except that here the short diameter of the prism is parallel to the bottom of the paper. Fig. 17 is a plan and end view of a rectangular block with a wide slot of the shape H I J K M L O N, cut through it lengthwise. The main point to which attention should be called here is that the line

C D is shaded, although the slot might be so deep that the light might not strike in there because of the shadow of the projecting lip marked in the side view G H I. Fig. 18 is a cross-section and end view of a circular cylinder with a large hole extending part way through and a smaller hole extending the rest of the way. The small circle in the end view is shaded, although it is so far in that no light could strike it.

The student should study these figures carefully, and before

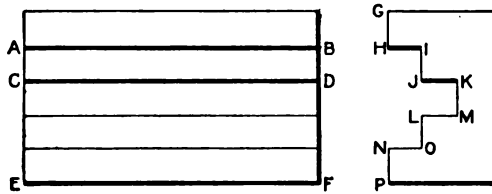


Fig. 17.

leaving them should understand what each figure means and how the shade lines are determined, so that when he meets similar forms in machine drawings he may know where the shade lines should be placed.

Dimensions. In giving the distance from one line to another, a dimension line is drawn between the two lines and arrowheads

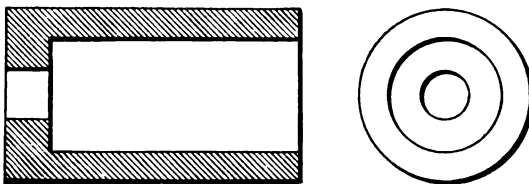


Fig. 18.

are placed at each end of the dimension line; the points of the arrowheads being *exactly on* the lines to which the measurement is being given. At a convenient place between the arrowheads a space is left in the dimension line for the figure.

Fig. 19 is a plan and elevation of a rectangular piece with a

cylinder on the center of its upper surface, and with four holes through it; the holes being symmetrically located with respect to the center line of the piece; that is, the holes A and B are just as far above the center line E F as C and D are below it, and the holes B and D are just as far to the right of the center line G H as A and C are to the left of it. The fact that the cylinder is on the center of the rectangular piece is shown by the lines E F and G H being drawn through the center of the circle in the plan view, these lines being the center lines both of the cylinder and of the rectangular piece. If the cylinder were not on the center, two other center lines would be drawn through the circle and the dimensions given from each of these lines to the center lines of the rectangular piece, or to the edges of the piece. The fact that the holes are symmetrically located is shown by the dimensions being given between the center lines of the holes and no dimensions being given from these center lines to the center lines of the piece.

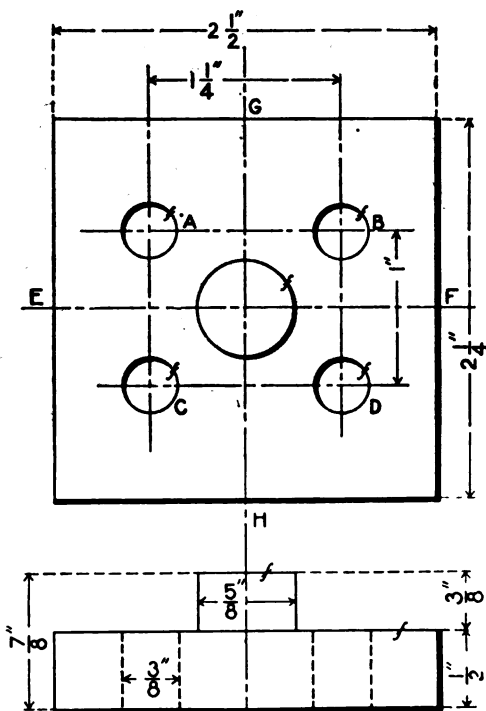


Fig. 19.

Fig. 20 shows how the piece might be dimensioned if the cylinder were not on the center of the rectangular piece and the holes were not symmetrically located with respect to the center of the rectangular piece.

If the centers of a set of holes are so located that a circle can be drawn through them, we always locate the holes by drawing a

center line circle through their centers and giving the diameter of this circle, and if no other dimension than this is given for the location of the holes, it is understood that they are equally spaced around this circle. Fig. 21 illustrates this. If the holes are not equally spaced around the circle, they may be located as shown in Fig. 22.

Diameters of circles, and of arcs of circles which are greater than semicircles, should be given rather than radii, but if the arc of the circle is less than a semicircle, its radius should be given.

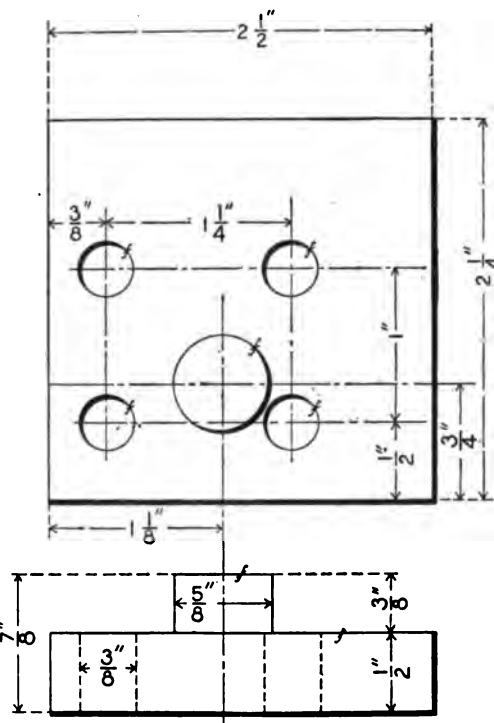


Fig. 20.

Fig. 23 shows how this should be done when the radius is large enough to permit; but if the radius is small, or the dimensions would interfere with other parts of the drawing, it may be done as in Fig. 24.

In Fig. 23 a small circle is drawn (free hand) around the center about which the arc is drawn, and a dimension line carried from the edge of this circle to the arc; an arrowhead being placed on the arc, and the figures placed in the dimension line in the usual way. In this case it is not necessary to put

the letter R (abbreviation for radius) after the dimension. In the two methods shown in Fig. 24 the R should be placed after the figures.

In putting dimensions on a drawing, the figures should be placed to read from only two sides of the paper, usually from the bottom for dimension lines which are horizontal, as the 2 1/4" dimen-

sion in Fig. 20, and from the right hand for dimension lines which are vertical, as the $2\frac{1}{4}$ " dimension in the same figure. Dimensions should never be placed on center lines if it can be avoided.

If a dimension is given in one view of an object, the same dimension need not be repeated in the other views.

In putting on fractions it is better to have the line which

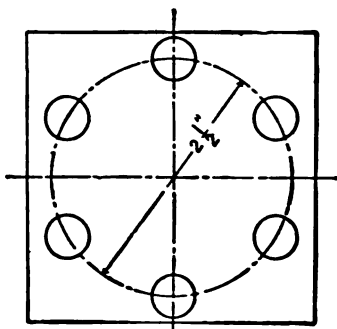


Fig. 21.

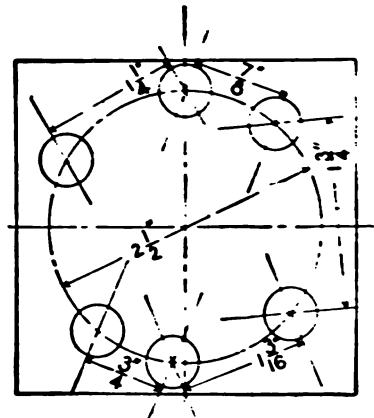


Fig. 22.

divides the numerator and denominator of the fraction extend in the same direction as the dimension line rather than at an angle: that is, the fraction would appear thus, $\frac{1}{2}$, rather than $\frac{1}{2}$.

Finished Surfaces. Since a working drawing is not only to

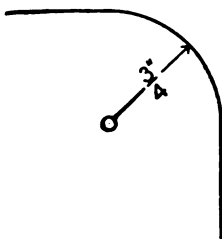


Fig. 23.



Fig. 24.

show the shape and size of the object which it represents, but is to describe it completely, it is essential that there should be some means of distinguishing between the surfaces of the object which are to be left rough as they come from the forge or from the foundry, and the surfaces which are to be finished. Any surface

which has been smoothed off in a lathe, planer, or any machine tool, or has been filed or scraped, is called a finished surface, and is indicated on a drawing by a letter placed on the *edge view* of this surface. In Fig. 19 the whole of the cylindrical part is finished, also the top of the rectangular part. The holes are also finished. The student should notice carefully how the finish marks are used to indicate this fact.

If a piece is to be finished all over, it should be marked “*f* all over.” If it is desired to specify what kind of finish is to be put on a surface, that is, whether rough turned, smooth turned, filed, scraped, etc., a note may be made to that effect.

On some conspicuous place on the drawing the words “*f* means finish” should be printed, so that there may be no misunderstanding on the part of a person examining the drawing.

Material. The material of which the piece is to be made should be indicated plainly. If any part of the drawing is a cross-section, the crosshatching might show the material, provided that in some conspicuous part of the drawing a sample of the crosshatching is shown and the material which it represents is stated. It is better, however, to mark on or near each piece, in plain letters, the material of which it is to be made.

Conventional Methods. In drafting, as in many other kinds of work, all unnecessary labor should be avoided. The drawing should give the instructions clearly, but need not be so elaborate as to require unnecessary time in the execution. It frequently happens that if an exact drawing were made representing every line of the object, a great deal of time would be required. Accordingly, if there is any way of representing an object by a few lines only, without sacrificing clearness, it should be used. There are many details such as screw threads, springs, bolts, etc., which occur so frequently on nearly all drawings that easy methods of representation have been universally adopted. In some cases, these ways of representing objects are approximations of the exact drawings and in other cases they are not. Such methods are called conventional methods, or conventions. For some details there is more than one convention, but the same convention should not be used for two different things, nor should several objects of the

same kind on the same drawing be represented conventionally by two different methods.

Screw Threads. The correct drawing of screw threads is a difficult part of mechanical drawing, but enough attention will be given it here to enable the student to make a simple working drawing which includes threads. The common conventional way of drawing a thread is shown in Figs. 25, 26, and 27. Fig. 25 being a single right-hand thread, and Fig. 26 a double right-hand thread.

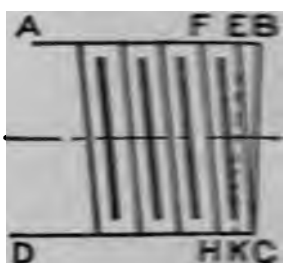


Fig. 25.

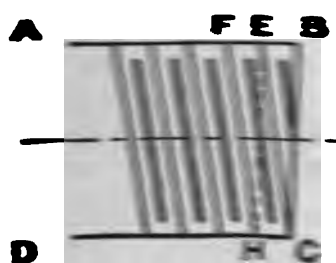


Fig. 26.

First, the plain cylindrical piece $ABCD$ is drawn as if there were no threads upon it. The thread is then indicated by the lines EC , FH , etc., with the shorter and heavier lines between. The lighter lines are all parallel and the same distance apart. This distance is not necessarily the same as the actual pitch of the thread on the screw itself, but is usually $\frac{1}{2}$ inch or $\frac{3}{4}$ inch in drawings of common sizes of bolts. The heavy lines are parallel to the lighter ones and midway between them. The angle which the lines make with the center line of the screw depends on the distance apart of the lines, the slant being such that for a single thread, Fig. 25, a line perpendicular to the center line through one end of one of the lighter lines, as E , will strike the opposite contour of the screw DC , at a point K , which is half way between C and H . To draw the lines so that they will have this slant, choose the distance FE , which is to represent the pitch, and space it off on either of the contour lines, as AB , starting anywhere (in the figure the starting point E is one-half of the distance FE away from B). Next, draw EK per-



Fig. 27.

pendicular to the center line, thus finding point K, and start the spacing on the contour (D) at a distance either side of K equal to $\frac{1}{2}$ FE.

The lighter lines can thus be drawn and the heavy lines put in parallel and half way between. The heavy lines should be a little shorter than the others, and, for the sake of neatness, all should be of the same length. The double thread, Fig. 26, is drawn similarly to the single thread, except that the slant is such that the perpendicular through E will pass through H.

After a little practice the student can draw the threads in this way with his triangles, getting the proper slant and the angle spacing by eye, without the necessity of measuring; he should practice with this end in view, for threads occur so frequently on drawings that the draftsman must be able to draw them rapidly.



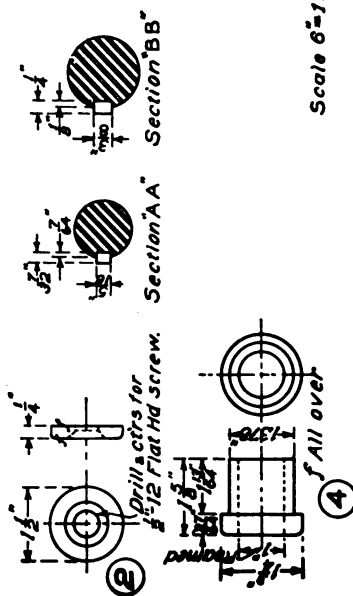
Fig. 28.

Notice should be taken of the fact that if the page be held so that the center lines of the screws in Figs. 25 and 26 are vertical, the lines which represent the threads slant downward from right to left. If the thread is left-handed the lines slant from left to right, as in Fig. 27.

In case of a long screw a few threads may be represented at each end and dotted lines carried the rest of the way, as in Fig. 28.

On any drawing of a screw which is intended for a working drawing, the pitch of the thread, or more commonly the number of threads for an inch of length should be specified; when the thread be standard, it is not always necessary to specify. Even in that case it is well to state the fact that the thread is standard. In giving the number of threads per inch it may be abbreviated, thus 12 THDS, or 12 TH. Examples of this will occur in what follows.

Threaded Holes and Invisible Threads. Fig. 29 shows a piece with a threaded hole in it. The hole is represented in the side view by the four parallel dotted lines. The distance apart of the two outer lines is equal to the diameter of the piece which is to be screwed into the hole. The inner lines are at a distance from



1	5 MCH.	6	NET 1/2" WIDE 1/2" THICK 35 1/2" LONG.
1	5 MCH.	7	NET 1/2" WIDE 1/2" THICK 1 1/2" LONG.
1	5 MCH.	8	1/2" COTTER PIN 1/2" LONG FOR #1.
1	5 MCH.	9	WASHER 2" DIA. HOLE 1/2" THICK FOR #1.
1	5 C R.	4	THIRD BUSHING FOR #1.
1	5 MCH.	3	1/2" 12 THD FLAT HD SCREW FOR #1 - 1 LONG.
1	5 MCH.	2	WASHER FOR #1.
1	5 MCH.	1	MOTOR SHAFT.

ARMATURE SHAFT

FIRST MADE FOR RT 4-B MOTOR.

DATE	REMAIN BY	TRACED BY
	FINISHED BY	INSPECTED

SPRAGUE ELECTRIC CO. M-250304
NEW YORK CITY.

Scale 6"=1 Ft.

TYPICAL WORKING DRAWING OF ARMATURE-SHAFT MADE IN THE DRAFTING ROOM OF THE SPRAGUE ELECTRIC CO.

the outer approximately equal to the depth of the thread. In the plan view of the piece (that is, the view looking at the end of the hole) the hole is shown by a full circle of a diameter equal to the distance apart of the inner dotted lines of the other view, and around this full circle a dotted circle whose diameter is equal to the diameter of the bolt; or, in other words, equal to the distance apart of the outer dotted straight lines. The dimension might be given on either view. In the figure it is given on the side view. In giving the diameter of a threaded hole, the diameter of the piece which is to be screwed into the hole is always given. In Fig. 29, the number of threads per inch is not stated, and in this case it would be understood to be standard. Fig. 30 shows another way of dimensioning a tapped hole, which is satisfactory and convenient.

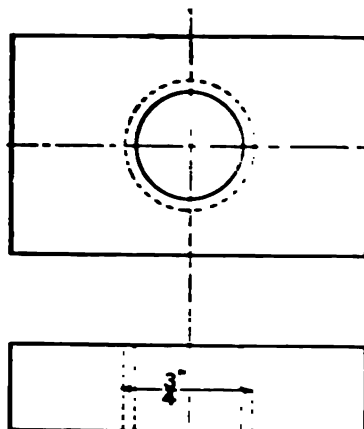


Fig. 29.

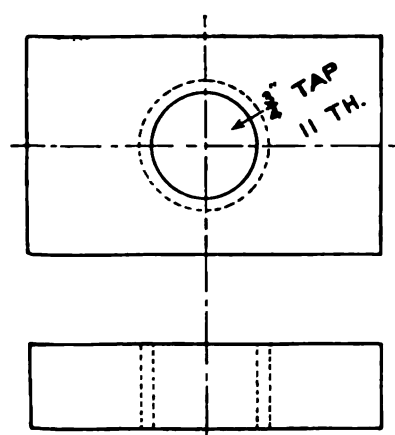


Fig. 30.

Fig. 31 shows the side view of the same piece as Fig. 29, with a part of the screw inserted in the hole. Attention is called to the fact that where the screw is hidden as it goes through the hole the thread is not shown, the parallel dotted lines representing the thread in the same manner as when the hole had no screw in it. Another point to be noted is that the cross-hatching of the broken ends for wrought iron is similar to the representation of the screw

thread and one must learn to judge when the light and heavy lines mean a thread and when they are cross-hatching.

Threads in Sectional Pieces. Figs. 32, 33 and 34 illustrate the common method of representing threads when they occur on pieces which are drawn in cross-section. Fig. 32 is the same piece as Fig. 29, shown cross-sectioned. The front half of the

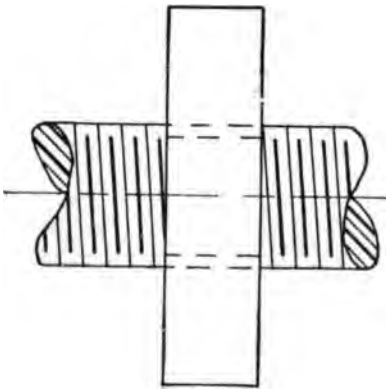


Fig. 31.

piece is supposed to be removed and we are looking at the back half. Now the thread on the back side of a screw slants the opposite way from what it does on the front side, and of course the same is true of the thread in a tapped hole. Consequently, since it is the back side of the hole which is seen, the slant of the lines which represent the thread is opposite to the direction they would have were we looking at the front side of the screw which goes into the hole. We have just learned that for a right-handed thread on a screw the lines slant downward from right to left, and therefore for a right-handed thread seen on the back side of a tapped hole, the lines will slant downward from left to right. In other words, for a right-handed thread in a hole which comes in a cross-section, the lines slant the same as they would on the front of a left-hand thread on a bolt; and for a left-hand thread in a sectioned hole, the slant is the same as for a right-hand thread on a bolt.

Fig. 33 is a piece which has a smooth hole through it and a

thread on the outside. Here the entire thread is invisible, except at the contour of the cylinder, and must be indicated by the notches. These are drawn by spacing off the distance which is used for the pitch and from the points thus found drawing lines with the triangle which make an angle of 60 degrees with the axis of the cylinder. For a single thread the notches on one side have their outer points opposite the inner points of the notches on the

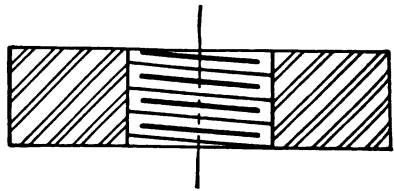


Fig. 32.

other side. For a double thread the notches are directly opposite each other.

Fig. 34 shows two ways of quarter-sectioning a threaded piece, the only difference being that on one the contour of the sectional part is drawn a straight line, while on the other the contour is notched. Either one may be used. The straight contour can, of course, be drawn much more quickly and in places where there is no danger of sacrificing clearness it should be used for that reason. If the drawing is somewhat complicated, so that without the notches it might not be quite clear that the piece was threaded, the notches should be used.

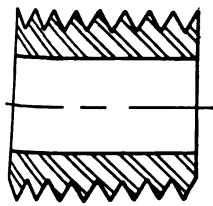


Fig. 33.

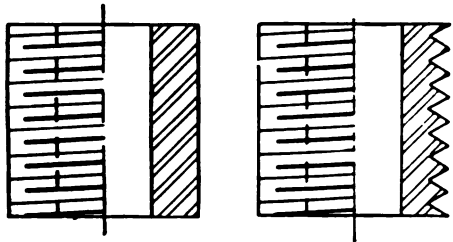


Fig. 34.

As has already been suggested, the student will doubtless find many other customs in the matter of drawing threads which are quite as good as the above. These have been given as ones which are common, and easily drawn. As a matter of convenience the following tables are given, which show the number of threads per inch on some of the most common sizes of bolts, according to the standard adopted by the United States Government, and the Whitworth or English standard.

UNITED STATES STANDARD SCREW THREADS.

Diameter of Bolt.	Threads per Inch.	Diameter of Bolt.	Threads per Inch.	Diameter of Bolt.	Threads per Inch.
$\frac{1}{4}$	20	$\frac{5}{8}$	11	$1\frac{3}{8}$	6
$\frac{5}{16}$	18	$\frac{3}{4}$	10	$1\frac{1}{2}$	6
$\frac{3}{8}$	16	$\frac{7}{8}$	9	$1\frac{3}{4}$	$5\frac{1}{2}$
$\frac{7}{16}$	14	1	8	$1\frac{7}{8}$	5
$\frac{1}{2}$	13	$1\frac{1}{8}$	7	2	5
$\frac{9}{16}$	12	$1\frac{1}{4}$	7		$4\frac{1}{2}$

WHITWORTH STANDARD SCREW THREADS.

Diameter of Bolt.	Threads per Inch.	Diameter of Bolt.	Threads per Inch.	Diameter of Bolt.	Threads per Inch.
$\frac{1}{4}$	20	$\frac{5}{8}$	11	$1\frac{3}{8}$	6
$\frac{5}{16}$	18	$\frac{3}{4}$	10	$1\frac{1}{2}$	6
$\frac{3}{8}$	16	$\frac{7}{8}$	9	$1\frac{5}{8}$	5
$\frac{7}{16}$	14	1	8	$1\frac{3}{4}$	5
$\frac{1}{2}$	12	$1\frac{1}{8}$	7	$1\frac{7}{8}$	$4\frac{1}{2}$
$\frac{9}{16}$	12	$1\frac{1}{4}$	7	2	$4\frac{1}{2}$

Bolts and Nuts. Among the most common pieces of machinery are bolts and nuts, and the draftsman has frequent occasion to draw them. Fig. 35 is a conventional drawing of a $\frac{1}{2}$ -inch bolt with a hexagonal head and nut. This figure shows the dimensions necessary to be given in order that a workman shall be able to make the bolt from the drawing.

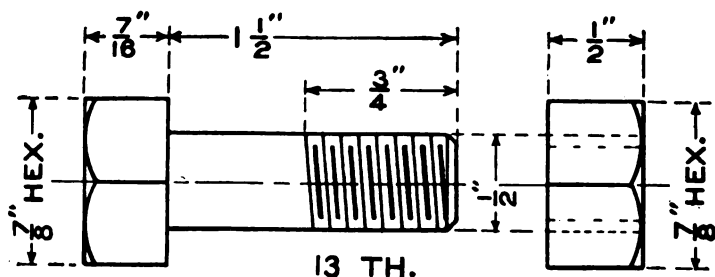


Fig. 35.

Beginning with the head of the bolt, let us study the various parts of this drawing in detail. The head is a hexagonal prism the end of which has been chamfered. We might expect that two views of the head would be necessary to completely define its shape, but the letters HEX printed after the dimension for the diameter of the head indicates that it is hexagonal. In like manner, if the head were square the letters SQ would be placed after the dimension. If two views were drawn, they would appear as in Fig. 36. The head is drawn as if the tool which cut the chamfer, cut off just the corners of the top, so as to make the top a circle tangent to the sides of the hexagon at B, E, G, etc.; the parts BCE, EFG, etc., being portions of a cone or sphere according to the manner of chamfering. The curves ABC and CEF are tangent to the line

GK in the side view, and the lines AJ, CD, and FH are all equal in length. The curves ABC and CEF are properly the lines of intersection of a cone or sphere, as the case may be, with the hexagonal prism, but a convenient and sufficiently accurate way of drawing them is by arcs of circles with the center on the line HJ, half way between HD and DJ, as indicated. The chamfer is represented in the end view by a circle inscribed in the hexagon.

It will be noticed that in Fig. 35 that view of the head is given which shows two faces of the prism, so that the shortest dimension of the hexagon is given. That is, the view is taken in the direction of the arrow L, Fig. 36, instead of in the direction of the arrow M.

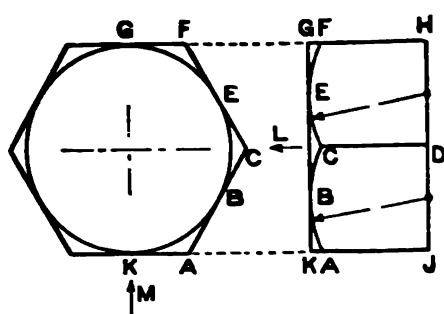


Fig. 36.

This rule should be followed on all detail drawings. The case when it is desirable to give a view in the direction of the arrow M will be discussed later.

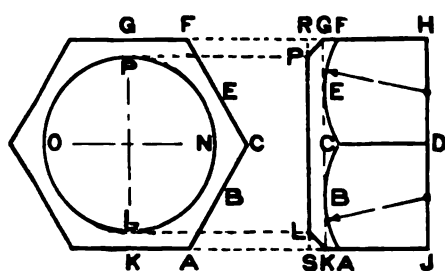


Fig. 37.

Sometimes it is desired to represent the chamfer as being greater, as in Fig. 37. To do this, draw the end view of the hexagon and inside it, of a diameter as much smaller as desired, draw the circle PNLO. Next draw the side view of the hexagonal prism as if there were

no chamfer, as shown at the right (partly in dotted lines). Then from P and L, the upper and lower points of the circle in the other view, draw lines perpendicular to RS and meeting it at P and L. From P and L draw PG and LK, either at an angle of 45 degrees or 30 degrees (the latter being preferable) with RS, and meeting the lines RH and SJ at G and K. Join G and K by a construction line GK (shown dotted but not to be left in the

finished drawing). Draw the arcs ABC and CEF with center on line HJ as shown, and tangent to GK.

Fig. 38 shows the proper way of representing the head which was shown in Fig. 36 if the view is taken in the direction of the arrow M. The dotted construction lines show how the widths are obtained. Fig. 39 shows the corresponding view of the head shown in Fig. 37. The radius with which the middle arc repre-

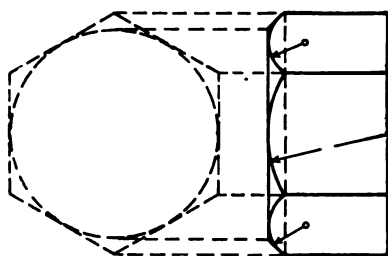


Fig. 38.

sented the chamfer is drawn in these two figures is apparent. Various rules are given for finding a radius for small arcs, but they can be found near enough by trial, after a little experience. The line TV, Fig. 39, to which the tops of the arcs are tangent, is drawn parallel to RS and at a distance from it equal to RG in Fig. 37.

The nut, Fig. 35, is drawn in exactly the same way as the head, so that what has just been said will apply equally well to the nut. The hole in the nut is indicated by the four parallel dotted lines as explained for Fig. 29.

The shank of the bolt is represented with the thread upon it as explained above for conventional threads. The point is drawn chamfered a little in the figure, so that it appears as the frustum of a cone. Bolts often have round points, in which case they would be shown as in Fig. 40. The lines which represent the thread should not cross the line which is drawn square across the bolt to indicate where the chamfer or the rounding of the point begins.

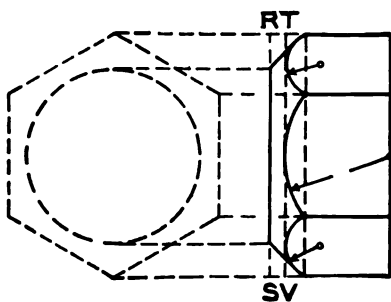


Fig. 39

Fig. 41 shows three views of a square head or nut with chamfer corresponding to that on the hexagonal head in Fig. 36; and Fig. 42 shows the square head or nut chamfered to correspond to

Fig. 37. Referring first to Fig. 41 the arc on the side view which shows the short diameter of the nut is drawn with a radius A, equal to two and one-quarter times the diameter of the bolt on which the head or nut belongs. The arcs on the other side view are drawn with a radius B, equal to one-half of A. The lines EF are drawn from points E tangent to the arcs, and it will be found that the points of tangency will come almost at the points where the arcs cut the lines CD. Points E are found by projecting from the plan view as indicated by the dotted lines. In Fig. 42, the construction is similar. The points N are first found by projecting from the top and bottom of the circle in the plan view; then the lines NL are drawn making angles of 30 degrees with line NN. (The proportions for the radii which are given, hold good only when the angle of 30 degrees is used). Next draw the construction line LL and draw the arc tangent to it with a

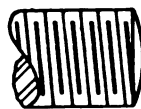


Fig. 40.

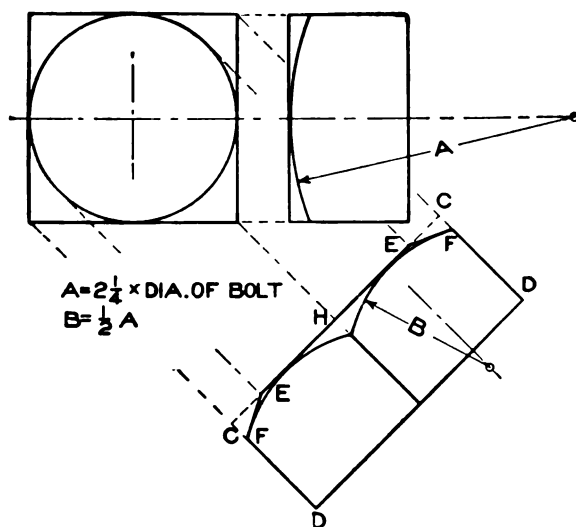


Fig. 41.

radius A equal to two and one-quarter times the diameter of the bolt, the same as in Fig. 41. To draw the chamfer in the other side view, draw the construction line parallel to and at a distance from CC equal to the distance LL from NN and draw the arcs

tangent to this line with radius B equal to one-half of A . The lines EF are then drawn as explained for Fig. 41.

Referring again to Fig. 35, the dimension which shows the length of the bolt under the head should be given to the extreme point of the bolt, as should also the dimension which shows how much of the bolt is threaded.

Most of the bolts in common use are made of standard sizes, that is, for a certain diameter of bolt there is a corresponding standard diameter and thickness for the head and the nut, and a standard number of threads per inch, so that if the bolt which the

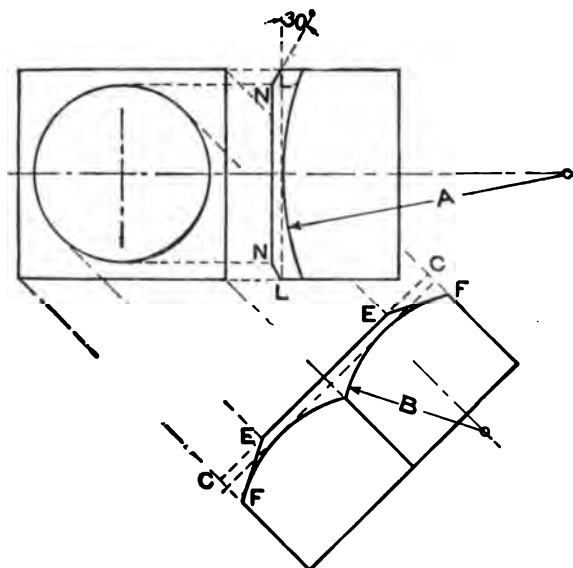


Fig. 42.

draftsman wishes to use has these standard dimensions they may be omitted from the drawing and a note made that the bolt is standard. Then the only dimensions necessary to be given are the diameter, the length under the head, and the length of the threaded part.

The following tables give the United States standard sizes of square and hexagonal heads and nuts for bolts. The columns headed "Width of Nut" and "Width of Head" give the shortest dimension of the square or hexagon, that is, the diameter of the

inscribed circle. The standard number of threads per inch can be found from the table already given.

SQUARE BOLT HEADS. U. S. STANDARD (Franklin Institute).

Dia. of Bolt.	Width of Head.	Thickness of Head.	Dia. of Bolt.	Width of Head.	Thickness of Head.
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	1	1 $\frac{5}{8}$	1 $\frac{3}{8}$
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{19}{64}$	$\frac{1}{8}$	1 $\frac{13}{16}$	1 $\frac{5}{8}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{1}{4}$	2	1
$\frac{7}{8}$	$\frac{25}{32}$	$\frac{25}{64}$	$\frac{3}{8}$	2 $\frac{3}{16}$	1 $\frac{3}{8}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	2 $\frac{3}{8}$	1 $\frac{3}{8}$
$\frac{9}{16}$	$\frac{31}{32}$	$\frac{31}{64}$	$\frac{5}{8}$	2 $\frac{9}{16}$	1 $\frac{9}{8}$
$\frac{3}{4}$	1 $\frac{1}{16}$	1 $\frac{7}{32}$	$\frac{3}{4}$	2 $\frac{3}{4}$	1 $\frac{3}{4}$
$\frac{7}{8}$	1 $\frac{1}{2}$	1 $\frac{5}{8}$	$\frac{7}{8}$	2 $\frac{15}{16}$	1 $\frac{5}{8}$
$\frac{1}{16}$	$\frac{1}{16}$	$\frac{23}{32}$	2	3 $\frac{1}{8}$	1 $\frac{9}{16}$

HEXAGON BOLT HEADS. U. S. STANDARD (Franklin Institute).

Dia. of Bolt.	Width of Head.	Thickness of Head.	Dia. of Bolt.	Width of Head.	Thickness of Head.
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	1	1 $\frac{5}{8}$	1 $\frac{3}{8}$
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{19}{64}$	$\frac{1}{8}$	1 $\frac{13}{16}$	1 $\frac{5}{8}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{1}{4}$	2	1
$\frac{7}{8}$	$\frac{25}{32}$	$\frac{25}{64}$	$\frac{3}{8}$	2 $\frac{3}{16}$	1 $\frac{3}{8}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	2 $\frac{3}{8}$	1 $\frac{3}{8}$
$\frac{9}{16}$	$\frac{31}{32}$	$\frac{31}{64}$	$\frac{5}{8}$	2 $\frac{9}{16}$	1 $\frac{9}{8}$
$\frac{3}{4}$	1 $\frac{1}{16}$	1 $\frac{7}{32}$	$\frac{3}{4}$	2 $\frac{3}{4}$	1 $\frac{3}{4}$
$\frac{7}{8}$	1 $\frac{1}{2}$	1 $\frac{5}{8}$	$\frac{7}{8}$	2 $\frac{15}{16}$	1 $\frac{5}{8}$
$\frac{1}{16}$	$\frac{1}{16}$	$\frac{23}{32}$	2	3 $\frac{1}{8}$	1 $\frac{9}{16}$

SQUARE AND HEXAGON NUTS. U. S. STANDARD (Franklin Institute).

Dia. of Bolt.	Width of of Nut.	Thickness of Nut.	Dia. of Bolt.	Width of Nut.	Thickness of Nut.
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	1	1 $\frac{5}{8}$	1
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{19}{64}$	$\frac{1}{8}$	1 $\frac{13}{16}$	1 $\frac{5}{8}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{1}{4}$	2	1 $\frac{1}{4}$
$\frac{7}{8}$	$\frac{25}{32}$	$\frac{25}{64}$	$\frac{3}{8}$	2 $\frac{3}{16}$	1 $\frac{3}{8}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	2 $\frac{3}{8}$	1 $\frac{3}{8}$
$\frac{9}{16}$	$\frac{31}{32}$	$\frac{31}{64}$	$\frac{5}{8}$	2 $\frac{9}{16}$	1 $\frac{9}{8}$
$\frac{3}{4}$	1 $\frac{1}{16}$	1 $\frac{7}{32}$	$\frac{3}{4}$	2 $\frac{3}{4}$	1 $\frac{3}{4}$
$\frac{7}{8}$	1 $\frac{1}{2}$	1 $\frac{5}{8}$	$\frac{7}{8}$	2 $\frac{15}{16}$	1 $\frac{5}{8}$
$\frac{1}{16}$	$\frac{1}{16}$	$\frac{23}{32}$	2	3 $\frac{1}{8}$	2

Pipes and Pipe Threads. The various kinds of pipe in common use are made to standard sizes, and as the draftsman very often comes in contact with piping we will consider it briefly. The kinds most often used are wrought-iron or steel pipe, brass pipe made to the size of wrought-iron pipe, and cast-iron pipe. The cast-iron pipe is made of different weights and form, according to the purpose for which it is to be used. Standard weight iron pipe is rated by its nominal inside diameter, although the actual diameter does not in most cases quite agree with the nominal diameter.

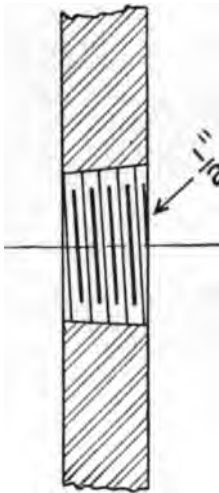


Fig. 43.

A $\frac{1}{4}$ -inch pipe is a pipe, the hole in which is supposed to be $\frac{1}{4}$ inch in diameter, but if carefully measured it will be found to be a few hundredths of an inch larger.

The threads on pipes and pipe fittings are also made to standard; taps and dies are made for various sizes of pipe. These taps and dies are spoken of or described by stating the size of the pipe for which they are intended. For example, a $\frac{1}{4}$ -inch pipe-tap is a tap of the proper size, shape, and number of threads per inch to cut the thread in a hole to receive a $\frac{1}{4}$ -inch pipe.

Threaded holes are made tapering for pipes, the standard taper being $\frac{3}{4}$ inch per foot, that is, the diameter of the hole decreases at the rate of $\frac{3}{4}$ inch per foot. In representing a hole which is threaded with a pipe tap, the hole is drawn of a diameter at its larger end about equal to the outside diameter of the pipe which is to be screwed into it, and is drawn tapering. It is well to make the taper considerably greater than the actual taper, so that the person looking at the drawing may see at a glance that the hole is for a pipe.

The thread is indicated in one of the conventional ways previously explained, but the number of threads per inch and the diameter of the hole need not be given; instead, a note is made

that the hole is tapped for a certain size pipe. Fig. 43 illustrates this.

The following tables of standards for wrought-iron pipe may be found convenient:

STANDARD SIZES OF WROUGHT IRON PIPE.

Nominal Size.	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Actual Inside Diameter.	.27	.364	.494	.623	.824	1.048	1.38	1.610	2.067
Outside Diameter.	.405	.54	.675	.84	1.05	1.315	1.66	1.90	2.375
Nominal Size.	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6	7	8
Actual Inside Diameter.	2.468	3.067	3.548	4.026	4.508	5.045	6.065	7.023	7.982
Outside Diameter.	2.875	3.50	4.00	4.50	5.00	5.563	6.625	7.625	8.625

STANDARD THREADS FOR WROUGHT IRON PIPE.

Nominal Size of Pipe.	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Threads per Inch.	27	18	18	14	14	$11\frac{1}{2}$	$11\frac{1}{2}$	$11\frac{1}{2}$	$11\frac{1}{2}$
Nominal Size of Pipe.	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6	7	8
Threads per Inch.	8	8	8	8	8	8	8	8	8

Scale Drawings. When the object which is to be drawn is not so large but that it can be easily actual size, or full size as it is called, on a sheet of paper which is of convenient dimensions, it is well, usually, to draw the piece full size. In most cases, however, the machine, or the building, or whatever is to be drawn is so large that it would be impossible to draw it full size. Then the drawing is made to some reduced scale, that is, all the dimensions are drawn smaller than the actual dimensions of the object itself; all dimensions being reduced in the same proportion. For example, if a piece is to be drawn half size, the distance from one point to another on the drawing would be one-half what it is on the piece itself; if the drawing is one-fourth size, the distance on the drawing would be one-fourth what it is on the piece itself.

and so on. In dimensioning such a drawing the dimension which is written on the drawing is the *actual dimension* of the piece, and not the distance which is measured on the drawing. This fact must be very clearly understood by the student.

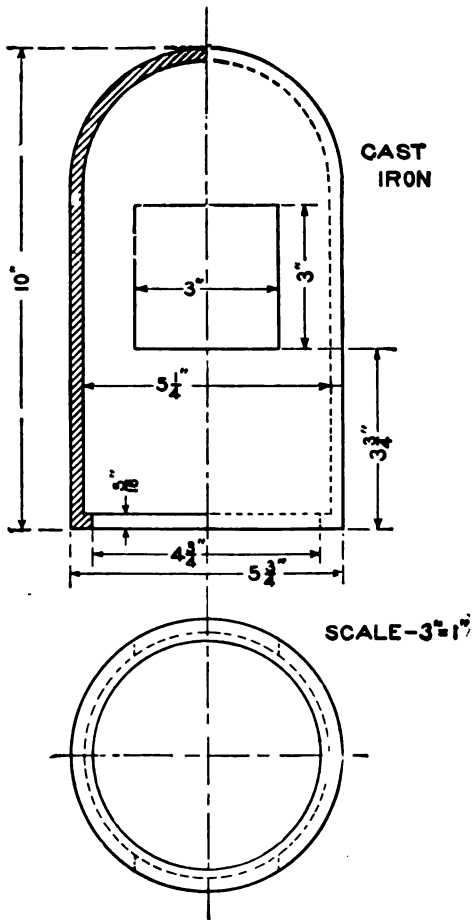


Fig. 41.

The common method of reducing all the dimensions in the same proportion is to choose a certain distance and let that distance represent one foot, this distance is then divided into twelve parts and each one of these parts represents an inch; then if half and quarter inches are required these twelfths are subdivided into halves, quarters, etc., until the subdivisions become so small that they cannot be used. We now have a scale which represents the common foot rule with its subdivisions into inches and fractions; but our new foot is smaller than the ordinary distance which we call a foot, and of course its subdivisions are proportionately smaller. When we make a measurement on the drawing we make it with our reduced

foot rule and when we make a measurement on the machine itself we make it with the common foot rule.

Draftsmen's scales can be bought which have different distances thus divided, so that if the draftsman wishes to draw a piece one-fourth size he looks over his scale until he finds a dis-

tance of three inches (which is of course one-fourth of a foot) divided as explained above, and he uses this to measure with on his drawing. His drawing would then be made to a scale of three inches to the foot. In the same way, if he wishes to make his drawing one-twelfth size he finds on his scale one inch divided into twelfths and fractions of twelfths and uses this as his standard of measurement; if he wishes to make his drawing one forty-eighth size he uses a quarter inch with its subdivisions. Sometimes if the piece to be drawn is very small, the drawing is made at an enlarged scale, such as twice size, three times size, etc.

The mistake of choosing the wrong distance to use on a scale is often made. For example, if he wishes to draw a piece $\frac{1}{4}$ size, he will look over his scale for a place marked $\frac{1}{4}$, and use this for his standard for $\frac{1}{4}$ size, which is wrong. The figure on the scale indicates the distance which is divided up to represent one foot, so



Fig. 45.

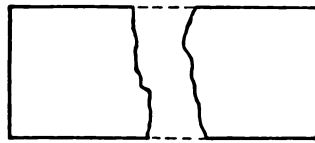


Fig. 46.

that the part of the scale which has $\frac{1}{4}$ marked on it means that $\frac{1}{4}$ of an inch is divided up into twelfths, or in other words, if a drawing is made according to that scale it will be $\frac{1}{32}$ th size.

Every drawing which is made at any other scale than full size should have the scale marked on it plainly.

Fig. 44 shows a piece drawn to a scale of 3 inches per foot, that is, $\frac{1}{4}$ size.

Long Pieces. A piece which is very long in proportion to its diameter or width is often difficult to draw complete, especially if there is much detail to any part of it, for if the scale is made so small that the length will go on a sheet of paper of convenient size the small part is so reduced that it is very small. If such a piece is plain the whole or part of its length, a portion of the plain part may be broken out on the drawing thus shortening the drawing of the piece so that a larger scale may be used. Of course in giving the dimension for the length, the *actual* length must be given. Fig. 45 shows a round piece thus broken out and Fig. 46 a rectangular piece.

It is a good idea to connect by dotted lines the two parts thus broken, although this is not essential.

“Turning Up” a Section. Sometimes a second view of a piece may be avoided by drawing on the first view a partial view showing the shape of the cross-section at the place where drawn. This partial view or “turned-up section” may be drawn in either full or dotted lines and should be cross hatched. If it comes where there are other lines of the original view, as is usually the case, the original lines would be drawn in regardless of the fact that they conflicted with the auxiliary view. Fig. 47 is an illustration.

In General. A working drawing will usually belong to one of the three following classes: *first*, a design of an entirely new machine; *second*, a drawing of a machine which is already built; *third*, a drawing of a new part to fit a machine which is already built, or a drawing of an old machine remodelled.

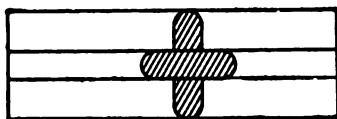


Fig. 47.

In order to design a new machine or a part of a machine, the draftsman must understand the principles of drawing and must also have a clear understanding of the work which the machine is to perform, and must know something of the principles of machine design and the strength of materials. A study of the general manner of proceeding with the drawing, when these things are known, will come later in this course. The draftsman may make a drawing of a machine which is already built, even if he has no understanding of the working of the machine, although under such conditions he works at a great disadvantage. In any case, he must know the principles of drawing.

If the student has learned thoroughly what has preceded in this course, he should be ready to take up the drawing from a machine, and we will now consider the general system to be followed in making such a drawing.

Sketches. In most cases it would be inconvenient for the draftsman to take his drawing board and instruments to the machine and make his careful drawing with the machine close at hand; preferably, he makes what are called sketches, carries his sketches to the drafting room and makes his drawing from them. In making the sketches, each piece of the machine should be

taken separately and a complete working drawing made of it, the only difference between these sketches and the finished drawing being that they are made largely without the use of instruments, triangles, etc.; that is, they are made free hand. The experienced draftsman will draw some lines and circles free hand, and use his instruments on some, according as he may think that he will save time by doing the one or the other; but it is well for the beginner to gain practice by making the sketches, almost wholly free hand, except large circles, and long lines.

The sketches should be neat and perfectly clear, so that if they are laid aside for a long time they can be clearly understood without depending at all upon memory. There is a strong tendency for the beginner to make his sketches hurriedly, thinking that when he comes to finish his drawing he can supply the details from memory. This is a bad plan and will lead to many mistakes. The sketches must be so clear and complete that anyone can read them who has never seen the machine. No attempt need be made to draw them to scale, but **all dimensions**, carefully measured from the machine, should be placed on the sketch.

After every piece of the machine has been thus sketched separately, it is well to make a rough, general sketch of the whole machine, to show how the various pieces fit together, a few of the most important over-all dimensions, distances between centers, etc.

All sketching should be done as rapidly as possible without sacrificing clearness. Before starting to sketch a piece, the draftsman must decide what views are necessary to describe the piece clearly. All sketches should be made large to avoid confusion.

Detail Drawing. After the sketches are made, the next step is the making of the pencil drawing from the sketches, accurately to scale. The size of the plate on which the drawing is to be made is usually fixed by some standard. Where many drawings are made and kept in an office, it is desirable to keep the plates of uniform size, as far as possible. It is good practice to have two or three standard sizes of plates, one for small drawings, one for ordinary-sized work, and one for large drawings; then, whenever a drawing is made, make it on one of these standard plates.

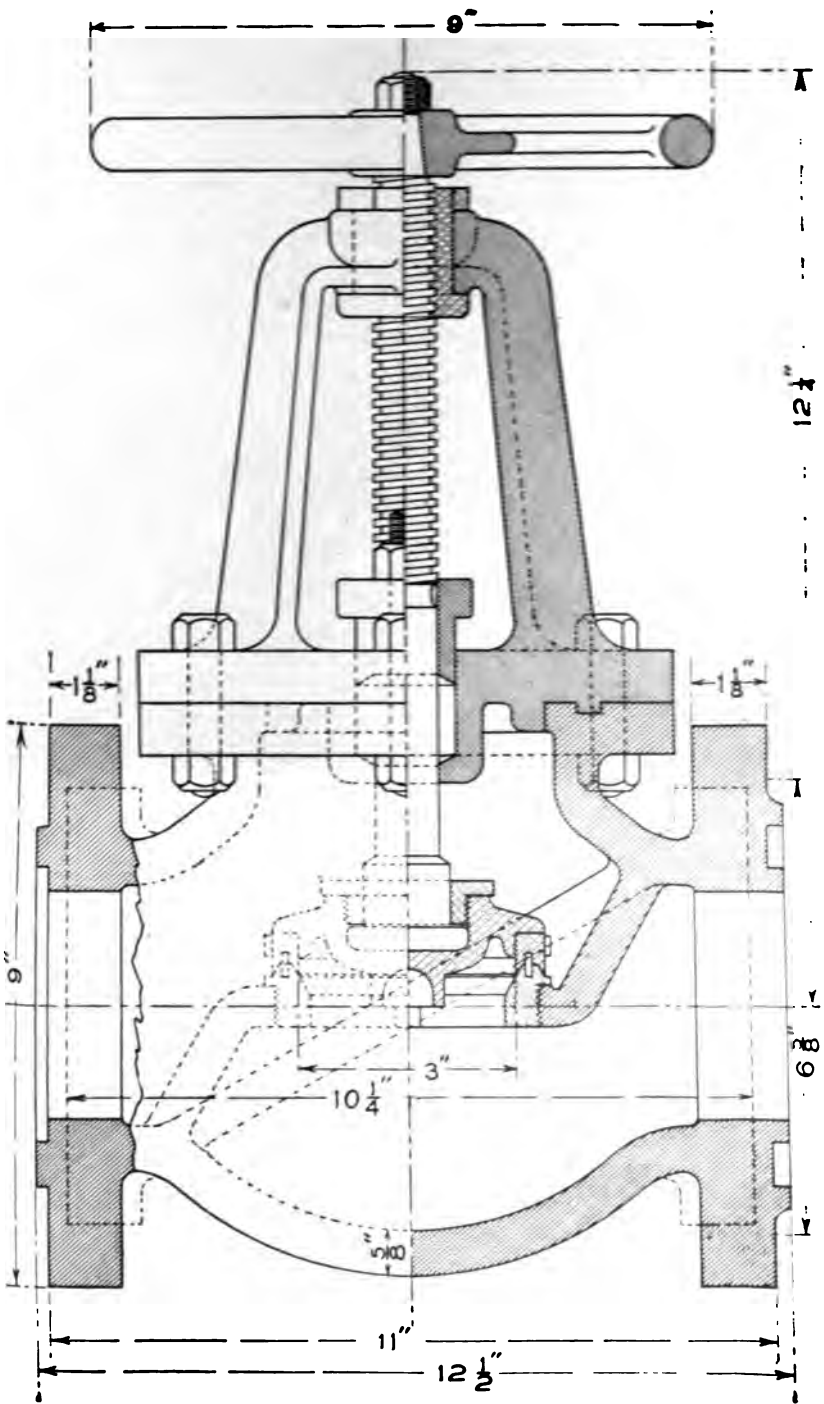
Assuming, then, that we have our paper stretched on the drawing board and the plate laid out, the next step will be to arrange the drawings of the various pieces on the plate so that

there will be room for all and so that they may be properly placed with relation to each other. It may happen that there will not be room on one plate for all the pieces, but that two or more plates will be required. When the parts must be thus arranged on different plates, an effort should be made to keep on the same plate those parts which belong together. For example, if we were drawing a lathe, the details of the parts of the head stock might form one plate, the apron another, and so on.

In locating the various pieces on a plate, they should be placed as nearly as possible in the same relative position to each other that they bear in the machine, except that they are separated. For example: if a nut belongs on the end of a screw, it is desirable to draw it on the same center line with the screw and at the end where it belongs. If a piece is vertical in the machine it should be vertical on the plate, and if horizontal in the machine, it should be horizontal on the plate.

The approximate location of the pieces on the plate may be easily decided by taking a small sheet of paper of about the same proportion as the plate, but perhaps one-fourth or one-half size, and sketching on it roughly the outline of the various pieces. The arranging of the plate should not be allowed to take much time, but should be done as rapidly as possible. After the location of each view of each piece is determined, the pencil drawing should begin (to scale) with one of the principal pieces. In almost all cases a center line is first drawn. It is better to carry along all the views of a piece at once, instead of completing one view at a time. The piece started should have all its views finished and completely dimensioned before another piece is begun; exceptions to this are sometimes necessary for special reasons. The lines should be drawn accurately, but no attempt need be made to obtain finish; that is, in order to save time, the lines may be run past the point where they should properly stop, etc. Nothing should be omitted, however.

Each plate of details should have a title, stating of what machine it is a drawing, and, if there are several plates, it is well to state also of what part of the machine the plate in question is a drawing. It is also a good idea to print its name beside each of the principal pieces.



WORKING DRAWING SHOWING PRINCIPAL DIMENSIONS OF SPRING SEAT VALVE.
Crosby Steam Gage & Valve Co.

Tracing. Having finished the pencil drawing, the next step is the inking. In some offices the pencil drawing is made on a thin, tough paper, called board paper, and the inking is done over the pencil-drawing, in the manner with which the student is already familiar. It is more common to do the inking on thin, transparent cloth, called tracing cloth, which is prepared for the purpose. This tracing cloth is made of various kinds, the kind in ordinary use being what is known as "dull back," that is, one side is finished and the other side is left dull. Either side may be used to draw upon, but most draftsmen prefer the dull side. If a drawing is to be traced it is a good plan to use a 3H or 4H pencil, so that the lines may be easily seen through the cloth.

The tracing cloth is stretched smoothly over the pencil drawing and a little powdered chalk rubbed over it with a dry cloth, to remove the slight amount of grease or oil from the surface and make it take the ink better. The dust must be carefully brushed or wiped off with a soft cloth, after the rubbing, or it will interfere with the inking.

The drawing is then made in ink on the tracing cloth, after the same general rules as for inking the paper, but care must be taken to draw the ink lines exactly over the pencil lines which are on the paper underneath, and which should be just heavy enough to be easily seen through the tracing cloth. The ink lines should be firm and fully as heavy as for ordinary work. In tracing, it is better to complete one view at a time, because if parts of several views are traced and the drawing left for a day or two, the cloth is liable to stretch and warp so that it will be difficult to complete the views and make the new lines fit those already drawn and at the same time conform to the pencil lines underneath. For this reason it is well, when possible, to complete a view before leaving the drawing for any length of time, although of course on views in which there is a good deal of work this cannot always be done. In this case the draftsman must manipulate his tracing cloth and instruments to make the lines fit as best he can. A skillful draftsman will have no trouble from this source, but the beginner may at first find difficulty.

Inking on tracing cloth will be found by the beginner to be quite different from inking on the paper to which he has been accustomed, and he will doubtless make many blots and think at

first that it is hard to make a tracing. After a little practice, however, he will find that the tracing cloth is very satisfactory and that a good drawing can be made on it quite as easily as on paper.

The necessity for making erasures should be avoided, as far as possible, but when an erasure must be made a good ink rubber or typewriter eraser may be used. If the erased line is to have ink placed on it, such as a line crossing, it is better to use a soft rubber eraser. All moisture should be kept from the cloth.

Blue Printing. The tracing, of course, cannot be sent into the shop for the workmen to use, as it would soon become soiled and in time destroyed, so that it is necessary to have some cheap and rapid means of making copies from it. These copies are made by the process of blue printing in which the tracing is used in a manner similar to the use made of a negative in photography.

Almost all drafting rooms have a frame for the purpose of making blue prints. These frames are made in many styles, some simple, some elaborate. A simple and efficient form is a flat surface usually of wood, covered with padding of soft material, such as felting. To this is hinged the cover, which consists of a frame similar to a picture frame, in which is set a piece of clear glass. The whole is either mounted on a track or on some sort of a swinging arm, so that it may readily be run in and out of a window.

The print is made on paper prepared for the purpose by having one of its surfaces coated with chemicals which are sensitive to sunlight. This coated paper, or blue-print paper, as it is called, is laid on the padded surface of the frame with its coated side uppermost; the tracing laid over it right side up, and the glass pressed down firmly and fastened in place. Springs are frequently used to keep the paper, tracing, etc., against the glass. With some frames it is more convenient to turn them over and remove the backs. In such cases the tracing is laid against the glass, face down; the coated paper is then placed on it with the coated side against the tracing cloth.

The sun is allowed to shine upon the drawing for a few minutes, then the blue-print paper is taken out and thoroughly washed in clean water for several minutes and hung up to dry.

If the paper has been recently prepared and the exposure properly timed, the coated surface of the paper will now be of a clear, deep blue color, except where it was covered by the ink lines, where it will be perfectly white.

The action has been this: Before the paper was exposed to the light the coating was of a pale yellow color, and if it had then been put in water the coating would have all washed off, leaving the paper white. In other words, before being exposed to the sunlight the coating was soluble. The light penetrated the transparent tracing cloth and acted upon the chemicals of the coating, changing their nature so that they became insoluble; that is, when put in water, the coating, instead of being washed off, merely turned blue. The light could not penetrate the ink with which the lines, figures, etc., were drawn, consequently the coating under these was not acted upon and it washed off when put in water, leaving a white copy of the ink drawing on a blue background. If running water cannot be used, the paper must be washed in a sufficient number of changes until the water is clear. It is a good plan to arrange a tank having an overflow, so that the water may remain at a depth of about 6 or 8 inches.

The length of time to which a print should be exposed to the light depends upon the quality and freshness of the paper, the chemicals used and the brightness of the light. Some paper is prepared so that an exposure of one minute, or even less, in bright sunlight, will give a good print and the time ranges from this to twenty minutes or more, according to the proportions of the various chemicals in the coating. If the full strength of the sunlight does not strike the paper, as, for instance, if clouds partly cover the sun, the time of exposure must be lengthened.

Assembly Drawing. We have followed through the process of making a detail drawing from the sketches to the blue print ready for the workmen. Such a detail drawing or set of drawings shows the form and size of each piece, but does not show how the pieces go together and gives no idea of the machine as a whole. Consequently, a general drawing or assembly drawing must be made, which will show these things. Usually two or more views are necessary, the number depending upon the complexity of the machine. Very often a cross-section through some part of the

machine, chosen so as to give the best general idea with the least amount of work, will make the drawing clearer.

The number of dimensions required on an assembly drawing depends largely upon the kind of machine. It is usually best to give the important over-all dimensions and the distance between the principal center lines. Care must be taken that the over-all dimensions agree with the sum of the dimensions of the various details. For example, suppose three pieces are bolted together, the thickness of the pieces according to the detail drawing, being one inch, two inches, and five and one-half inches respectively; the sum of these three dimensions is eight and one-half inches and the dimensions from outside on the assembly drawing, if given at all, must agree with this. It is a good plan to add these over-all dimensions, as it serves as a check and relieves the mechanic of the necessity of adding fractions.

FORMULA FOR BLUE-PRINT SOLUTION.

Dissolve thoroughly and filter.

- | | | |
|----|------------------------------|------------|
| A. | Red Prussiate of potash..... | 2½ ounces, |
| | Water..... | 1 pint. |
| B. | Ammonio-Citrate of iron..... | 4 ounces, |
| | Water..... | 1 pint. |

Use equal parts of A and B.

FORMULA FOR BLACK PRINTS.

Negatives. White lines on blue ground; prepare the paper with

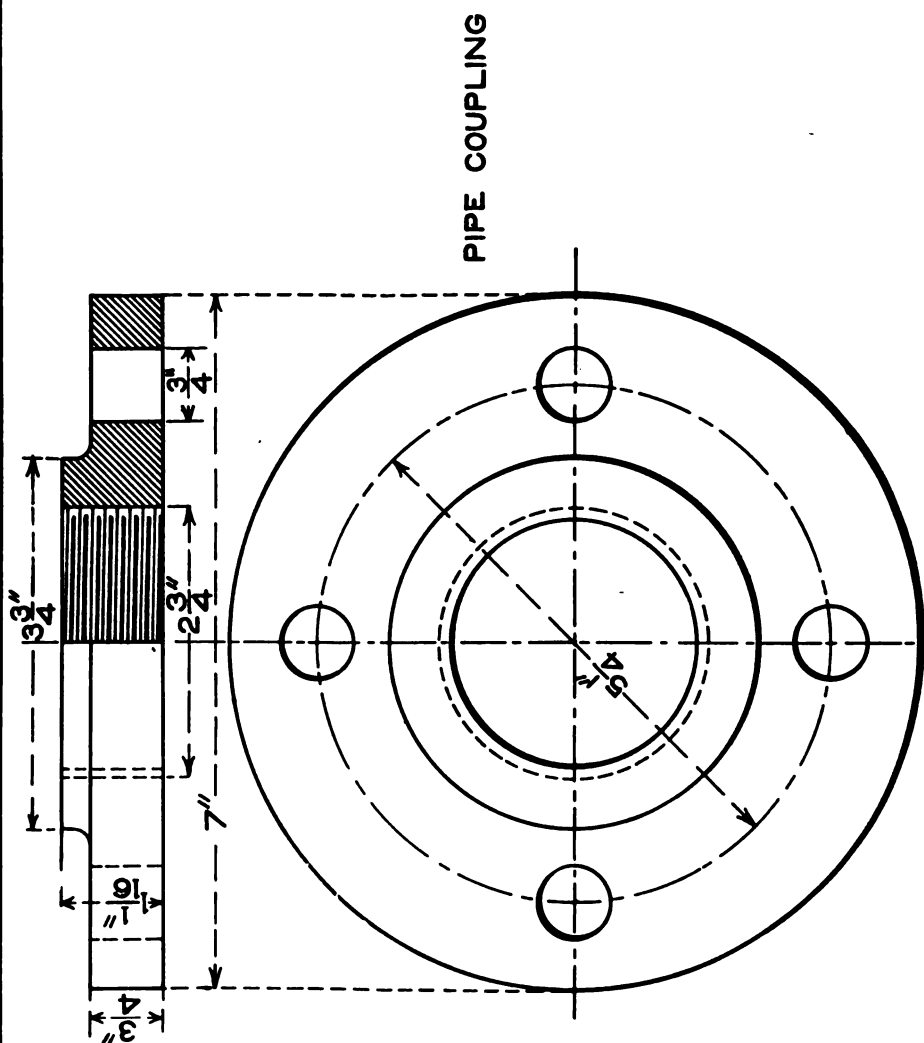
- | | |
|------------------------------|------------|
| Ammonio-Citrate of iron..... | 40 grains, |
| Water..... | 1 ounce. |

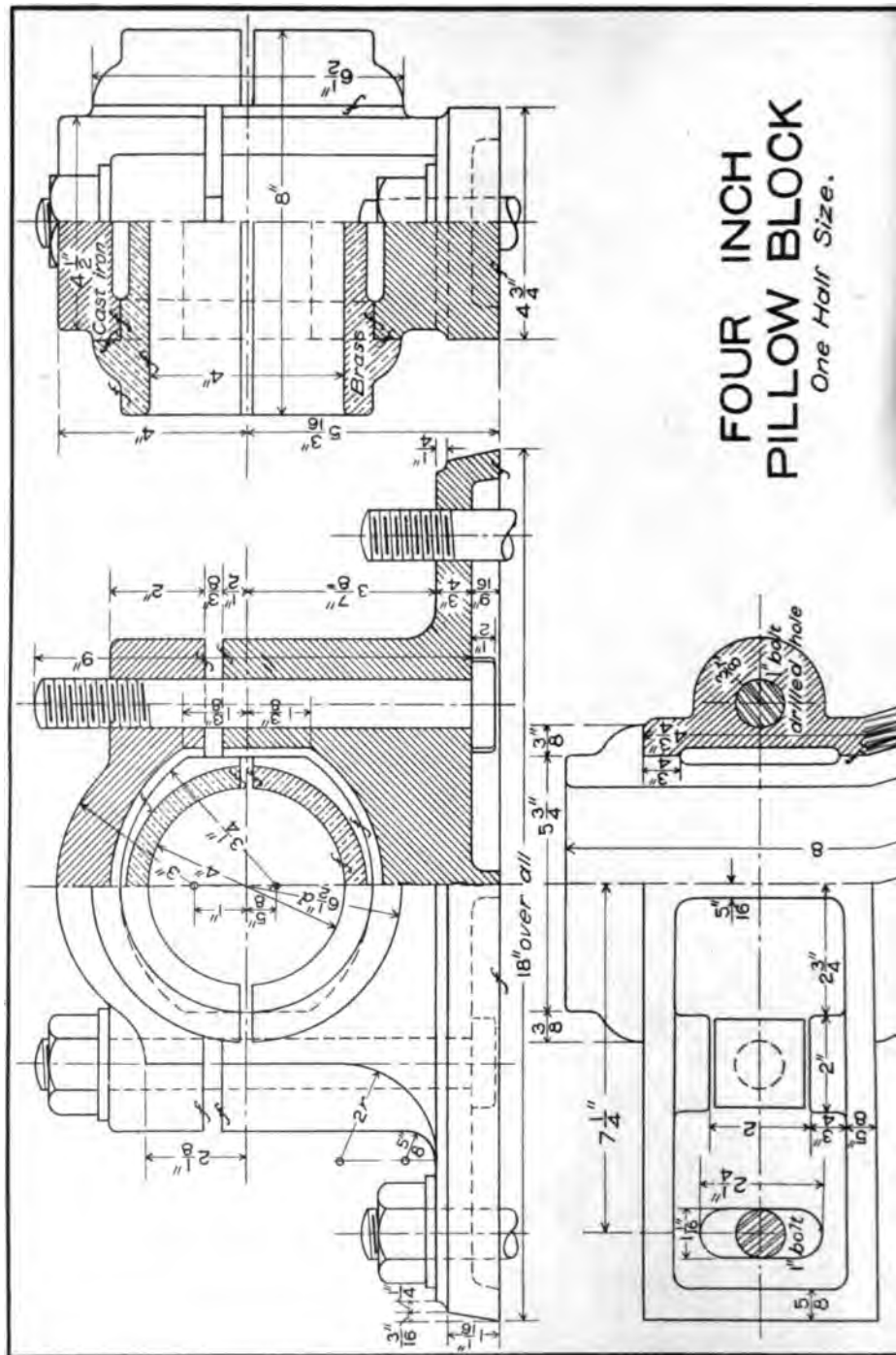
After printing wash in water.

Positives. Black lines on white ground; prepare the paper with:

- | | | |
|-----------------------|------------------|-----------|
| Iron perchloride..... | 616 grains, | |
| Oxalic Acid..... | 308 grains, | |
| Water..... | 14 ounces. | |
| Develop in { | Gallic Acid..... | 1 ounce, |
| | Citric Acid..... | 1 ounce, |
| | Alum..... | 8 ounces. |

Use 1½ ounces of developer to one gallon of water. Paper is fully exposed when it has changed from yellow to white.





PLATES.

PLATE XVI.

Pipe Coupling. The drawing represents one of a pair of cast-iron couplings used for connecting two lengths of pipe. It is threaded for a right-handed thread, but appears left-handed because the back part of the thread is visible in the section.

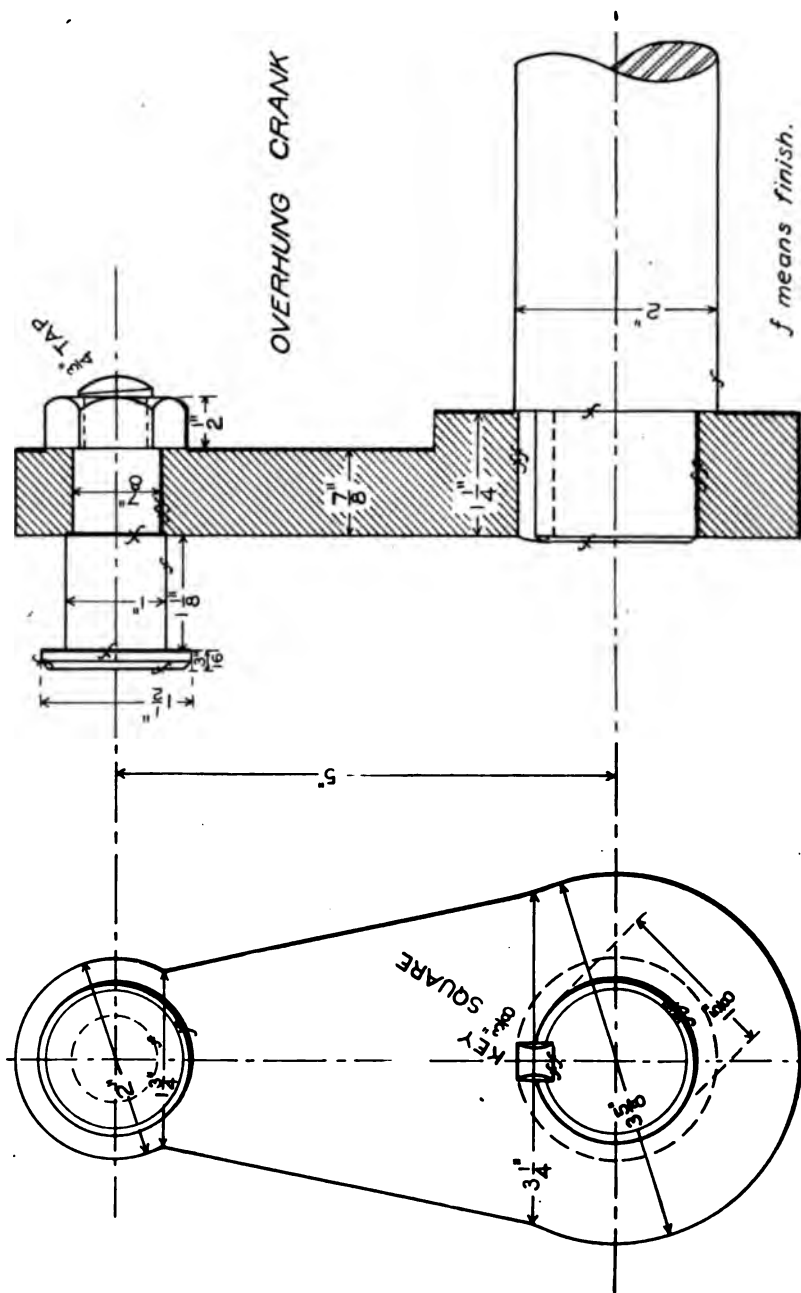
The vertical center line of the coupling is in the center of the plate; the center of the plan is $3\frac{1}{2}$ inches from the lower border and the bottom of the elevation $1\frac{1}{2}$ inches from the top border line. The elevation is made in half section, that is, the right-hand half. It is made by imagining that the front right quarter of the coupling is cut away by vertical planes. If the cutting plane passes through a hole or opening the cross-hatching is omitted. The dotted lines at the left of the hole show that it is threaded. The distance between these lines is $\frac{3}{8}$ inch, the depth of the thread. The threaded or tapped portion is shown in plan by the two circles, the dotted circle representing the outside and the full circle the inside or root of the thread.

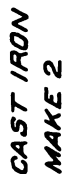
The boss or hub adds to the strength and allows more threads. The shade lines should be placed on the drawing following the custom for shop drawings. The title "Pipe Coupling" should be placed as shown and made with letters $\frac{1}{4}$ inch high. The letters may be either vertical or inclined Gothic capitals.

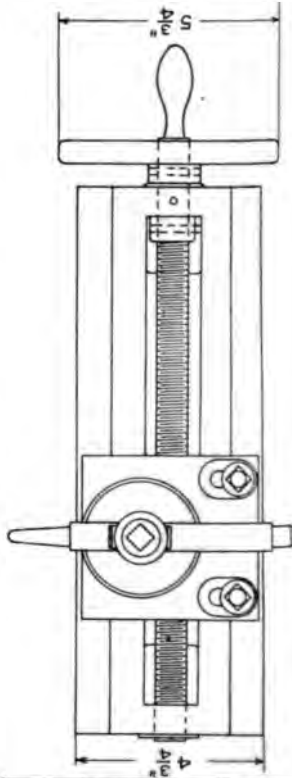
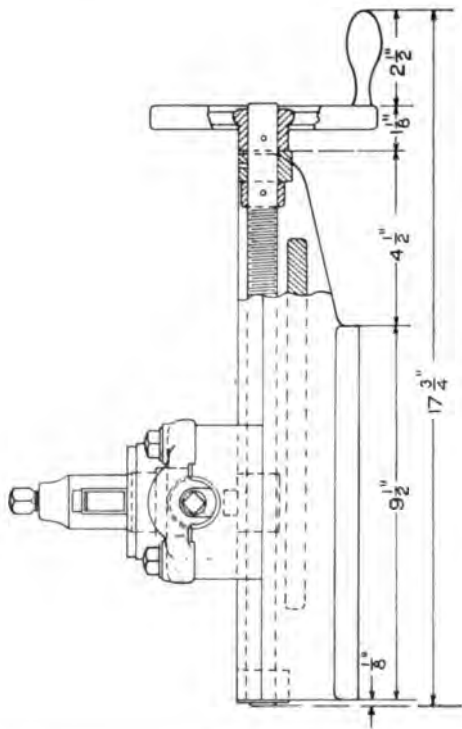
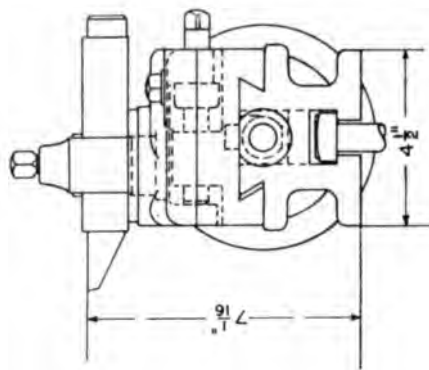
PLATE XVII.

Pillow Block. The drawings for this plate are three views—side, plan and end—of a 4 inch-pillow block. Each view is half in section. The drawing should be one-half size. Make the vertical center line of the side and plan views $4\frac{3}{4}$ inches from the left-hand border. The horizontal center line of the side view should be $2\frac{3}{8}$ inches from the top border line and the horizontal center line of the plan $2\frac{1}{4}$ inches from the bottom border line. Locate the vertical center line of the end view $2\frac{1}{4}$ inches from the right-hand border line; the horizontal center line will of course be a continuation of that of the side view. Note that the left-hand half of the plan represents what is seen by looking up from below. The cutting plane for the right-hand half passes horizontally through the center of the shaft.









ASSEMBLY COMMUTATOR TURNING TOOL

FIRST MADE FOR APPRENTICE COURSE
DESIGN BY AG. J. H. HALL, JR. 20 18
PATENTED BY AG. J. H. HALL, JR. 20 18
GENERAL ELECTRIC CO. MI70620

EXAMPLE OF SHOP DRAWING MADE IN DRAFTING ROOM OF THE GENERAL ELECTRIC COMPANY.

MECHANICAL DRAWING.

PART V.

MACHINE DRAWING.

A machine consists of a number of parts, or groups of parts, so arranged and connected that when power is applied at one part, definite motions and forces are transmitted to the other parts, which in turn do certain definite work. The parts of a machine may be divided in a general way into two classes: first, those parts which have or cause motion; and second, those which act as supports for the moving parts, such as frame, bearings, etc.

One of the groups of parts of a machine, arranged to accomplish some one particular result, is called a mechanism. Most machines are composed of several mechanisms, one doing one thing and another doing something else, and the whole working together to do the work for which the machine is designed. Take, for example, a metal planer; the gears, levers, etc., which cause the platen to move back and forth form one mechanism; the parts which feed the tool across form another mechanism; and so on, all the mechanisms taken together forming the machine.

Among the most common parts of machines are springs, screws, cams, pulleys and belts, and gears, and consequently it is necessary that a draftsman should understand how to draw these parts.

THE HELIX.

Since most coil springs and all screw threads depend upon a curve known as a helix, it will be necessary to know what a helix is, and how it can be drawn, before taking up the construction of the springs and screws.

Suppose we take a cylindrical piece of wood, such as is shown in Fig. 1, and a rectangular piece of paper, A B F E, with the side A B equal to the circumference of the cylinder, and the side A E equal to the length of cylinder. If we lay off along A E any convenient distance, A D, and draw the line D C parallel to A B

we have the rectangle $A B C D$. Now draw the diagonal, $A C$, of this rectangle and wrap the paper around the cylinder, keeping the side $A E$ on an element of the cylinder; the paper will just cover the cylinder, the edge $B F$ meeting the edge $A E$. The point C coincides with point D , and is on the same element of the cylinder as A ; therefore the line $A C$ has made one complete turn around the cylinder, advancing the distance $A D$ in this turn. The curve which the line $A C$ now takes is called a helix, and the distance $A D$ is called the pitch of the helix.

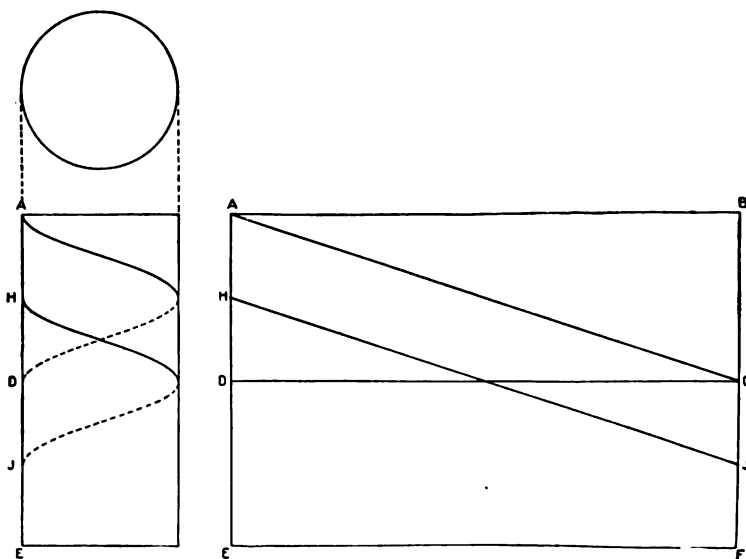


Fig. 1.

If on the piece of paper we also choose a point, H , halfway between A and D , and draw from this point a line, $H J$, parallel to line $A C$, this line $H J$ will form another helix parallel to the helix found by the line $A C$, when the paper is wrapped around the cylinder. The pitch of both helices is the same.

The helix is often incorrectly called a spiral, but there is a marked difference between the two; the spiral is a curve which lies in one plane, and winds around a point, constantly receding from the point, according to some law. The mainspring and hairspring of a watch are in the form of spirals.

To draw the projections of a helix we must know the diameter of the cylinder about which the helix is wound, and the pitch of the helix. Fig. 2 shows the construction. Draw two projections of the cylinder $A B D C$; along any element, preferably one of the contour elements, $A B$ or $C D$, lay off the pitch $A E$. Divide the circumference of the circle, which is the end view of the cylinder, into any number of equal parts, and number the points of division 1, 2, 3, etc. Divide the pitch $A E$ into the same number of equal parts, and number these points of division in the same way that the points on the circle are numbered, calling

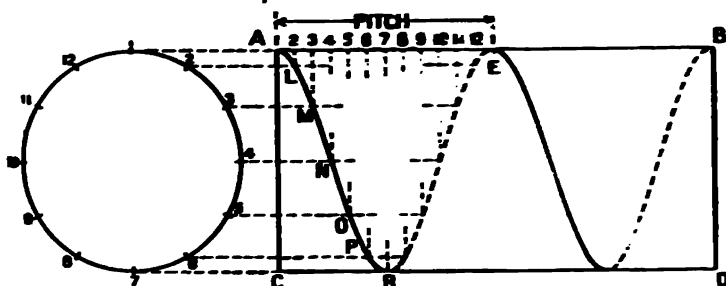


Fig. 2.

the point A No. 1. From point 2 on the circle draw a line parallel to $A B$, and from point 2 on $A B$ draw a perpendicular to $A B$. The point, L , where the parallel line meets the perpendicular line, is one point on the projection of the helix. The points M, N , etc., are found in the same manner. A smooth curve starting from A , going through all the points and ending at E , will be the projection of one turn of the helix. The half from A to R is on the front, and is therefore a full line, while the half from R to E is on the back and is a dotted line. It should be observed that the point R is on the perpendicular from 7, which is just halfway between A and E , that is, the distance $C R$ is just one-half the pitch. The curve from E to B is the projection of the next turn of the helix and is exactly like the first one.

The helix shown in Fig. 2 is called a right-handed helix. If the curve starts at C and is drawn as in Fig. 3, we have a left-handed helix. Notice that the visible part (from C to R) slants

in the same direction as the invisible part of the right-handed helix, which is shown dotted in Fig. 2.

Since the helix is a line drawn on the surface of a cylinder, the other projection of the helix must be the circumference of the circle, which is the end view of the cylinder. Fig. 4 shows a right-handed double helix, and Fig. 5 is a right-handed triple helix.

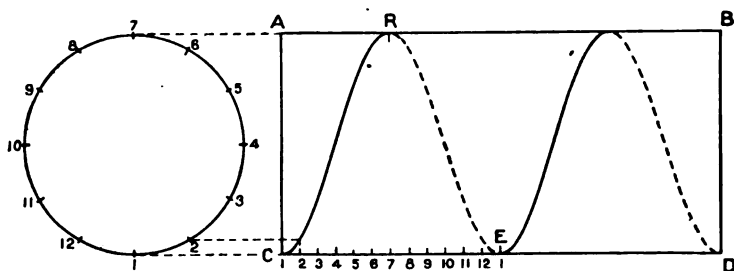


Fig. 3.

The construction of these curves should be studied carefully in order that the springs and screw threads may be better understood.

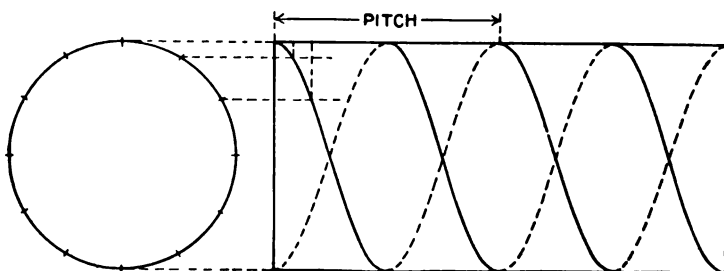


Fig. 4.

Helical Springs. If, instead of winding a line around a cylinder in the form of a helix, as shown in the preceding figures, we wind a piece of spring wire, we will get a helical spring.

Fig. 6 is the drawing of a helical spring of round wire, the side view only being drawn, as this is all that is necessary to give all the dimensions. To draw the spring we must know the pitch,

the diameter of the wire, and either one of the dimensions, A, B or C. If A is given, we subtract from A the diameter of the wire to find B; and if C is given, we add to C the diameter of the wire to get B; then knowing B and the pitch we can draw the helix (which is shown in dotted lines) exactly as the helix was drawn in Fig. 2. This is the helix formed by a line in the center of the wire. Now draw a series of circles with centers on this

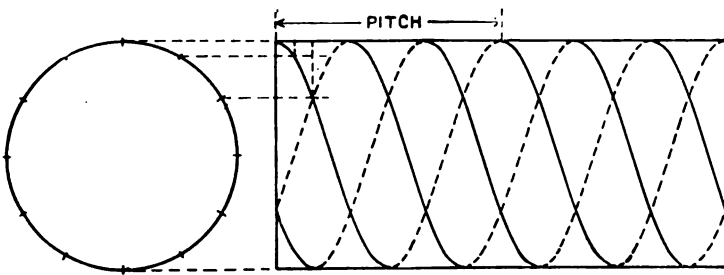


Fig. 5.

helix and of a diameter equal to the diameter of the wire. Smooth curves drawn tangent to these circles, as shown in the figure, will give the projection of the spring.

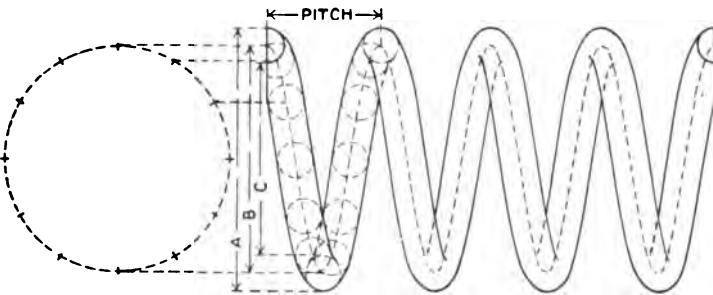


Fig. 6.

Fig. 7 shows a helical spring of square wire. The drawing of this is simply the drawing of four helices, starting from each of the corners of the square, A C M L; this square being the cross-section of the wire of which the spring is made. All four of the helices have the same pitch, equal to A B, for since the square

B D P N is the same as A C M L, the distance C D is the same as A B ; and since the points L, M, N and P are vertically under A, C, B and D, respectively, the distance L N is equal to A B, and

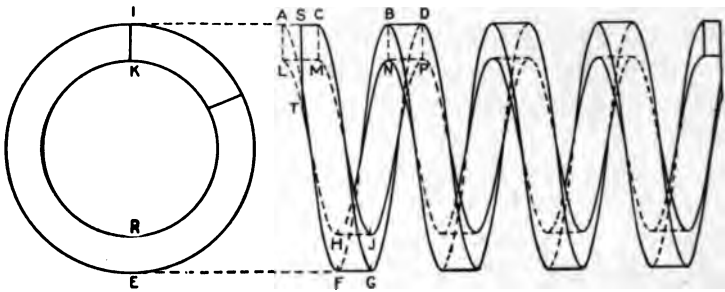


Fig. 7.

M P is equal to C D. The helix A F B has a diameter equal to that of the circle I E and is drawn by dividing the circle I E and the pitch A B, as in Fig. 2; and the helix C G D, having the same diameter as A F B, is drawn by dividing circle I E and pitch C D. The helix L H N has a diameter equal to that of the circle K R, which is I E minus twice the diameter of the wire, and is drawn by dividing up the circle K R and the pitch L N; and the

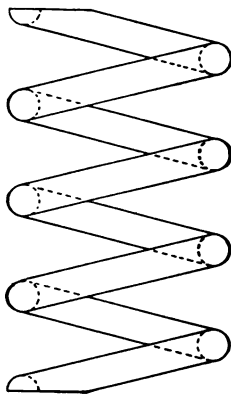


Fig. 8.

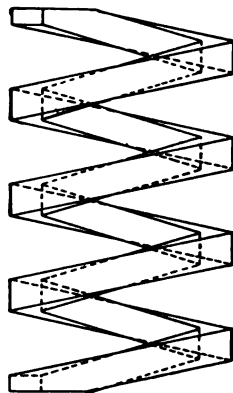


Fig. 9.

helix M J P, having the same diameter as L H N, is drawn by dividing circle K R and pitch M P. Since the two circles are drawn about the same center, the divisions on circle K R can be found by drawing radial lines from the points of division on circle

I E. The vertical lines drawn from the divisions of the pitch A B can be used for the divisions of L N, and those drawn from divisions of C D can be used for M P.

After the four parallel helices are drawn it is necessary to study the drawing carefully to decide what lines will be visible (full lines) and what invisible (dotted lines). Dotted lines should be used from H to J, N to P, etc., and full lines from F to G, B to D, etc. The line S T is the end of the spring, and consequently any part of a helix which goes outside of that line should not be left on the finished drawing. It is better, however, to draw in the whole of the square A C M L and to draw the helices starting from A and L in order to draw those parts of the same helices which lie to the right of S T. The parts to the left of S T are shown in the figure by light dotted lines to indicate that they are construction lines, and not a part of the projection of the spring itself.

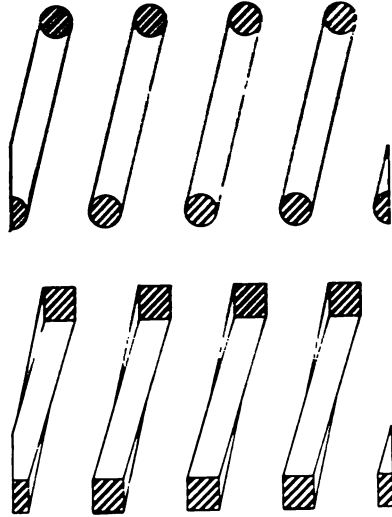


Fig. 10.

Conventional Representations of Springs. To draw springs by the method just explained involves considerable work and would consume

a great deal of time if many were to be drawn, therefore in working drawings the draftsman frequently uses a conventional method. This conventional drawing is similar to the true projection, except that straight lines are used in place of curved lines. Fig. 8 shows the conventional drawing of a spring of round wire, and Fig. 9 of a spring of square wire. Springs are often shown in half-section, as in Fig. 10, this method involving less work than the method of Figs. 8 and 9.

SCREW THREADS.

If we cut a groove around a cylinder in the form of a helix we shall have what is called a screw thread, the thread being

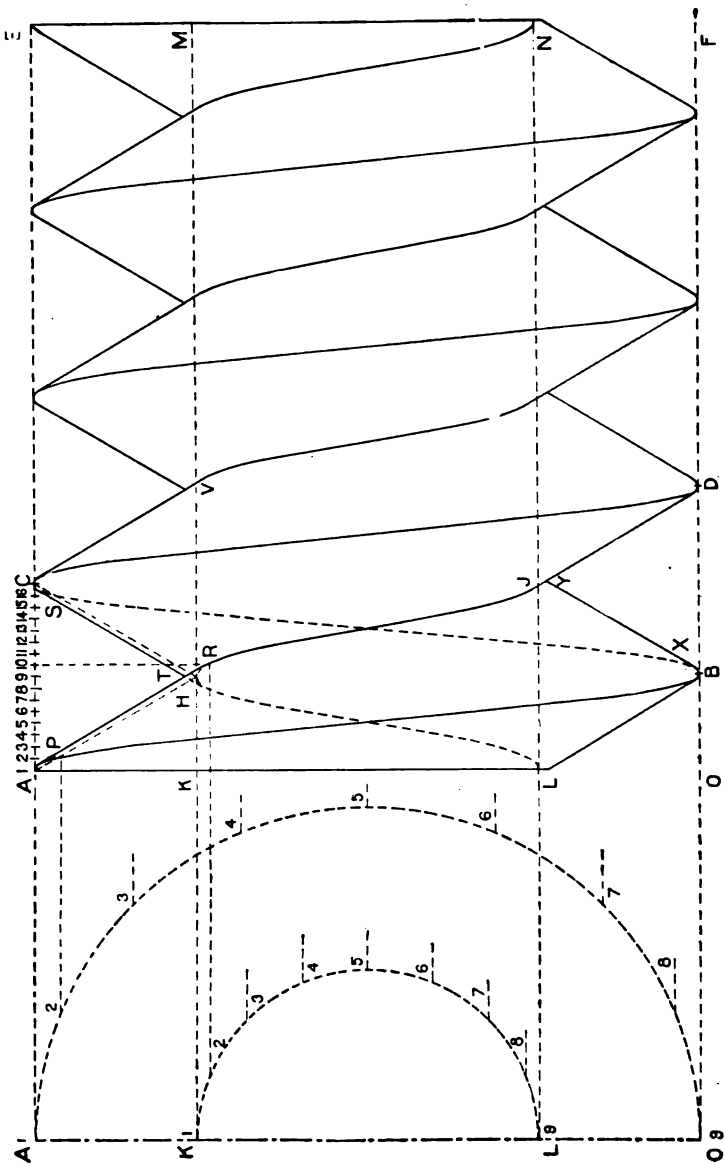
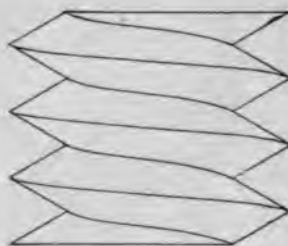


Fig. 12. Construction of V Thread.

MECHANICAL DRAWING.

formed by the material which is left between the successive turns of the helical groove. A cylinder having such a helical groove cut around it is called a screw, and a piece having a hole in it with a helical groove cut around the hole is called a nut. The most common uses of the screw are to fasten pieces together or hold them at a given distance apart, and to cause one piece to move with relation to another piece.

V Thread. The form of screw thread with which we are most familiar is what is known as the V thread, shown in its simplest form in Fig. 11. Fig. 12 shows the method of drawing the true projections of this thread. The dimensions which must be known in order to make the drawing are the outside diameter, A O, the pitch, A C, and the depth of the thread, A K. First draw the two projections of a cylinder of a diameter equal to the outside diameter of the screw. Half of the end view is sufficient. On the line A E of this cylinder lay off A C equal to the pitch, and starting at A draw the helix A B C D, as described for Fig. 2. Inside of the cylinder A O, draw a smaller cylinder, K L, the diameter of which is equal to the diameter A O minus twice



LEFT-HAND THREAD.



RIGHT-HAND THREAD.

Fig. 11.

the depth of the thread. Now on this smaller cylinder, starting at point H, perpendicularly under a point on the line A C which is halfway from A to C, draw the helix H J V with the same pitch as was used for the helix A B C. Draw the lines P R, X Y, S T, etc., tangent to the two helices, and the projection of the thread is completed. It is necessary to draw the invisible parts of the two helices in order to draw the lines S T, X Y, etc., but they need not be left on the finished drawing. In Fig. 12 they are shown dotted for one turn of the screw in order to show the construction.

Fig. 13 shows the method of drawing a double V thread.

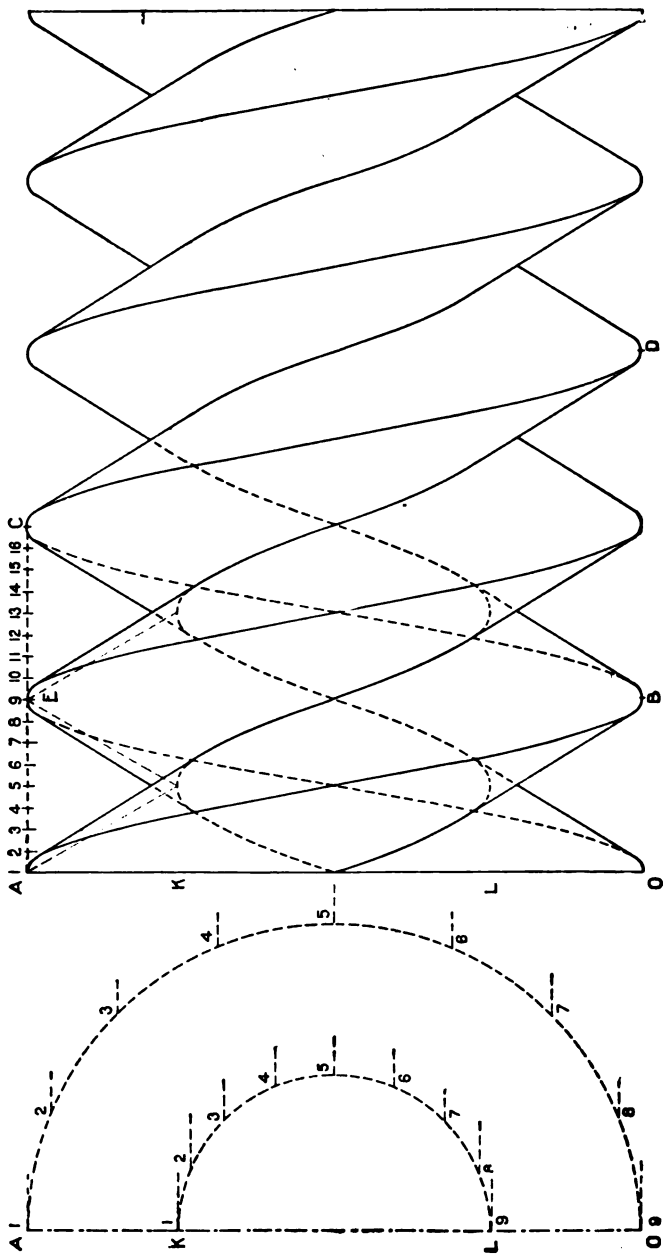
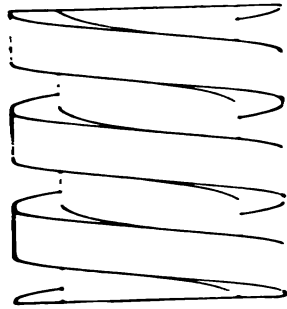


Fig. 13. Construction of Double V Thread.

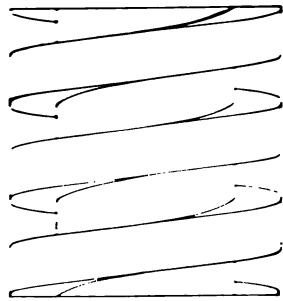
The process is exactly the same as for drawing a single thread. Start at point A and draw the single thread A B C D exactly as in Fig. 12; then start at point E, halfway between A and C, and draw another single thread of the same pitch as the first one. Some thought may be necessary to decide when the lines of one thread become hidden behind the other thread.

Square Thread. Another very common form of screw thread is that shown in Fig. 14, and is known as the square thread. The method of drawing this thread is similar to that for the V thread with the exception of a few minor points. The construction is shown in Fig. 15. The dimensions which must be known are the outside diameter, A O, the pitch, A C, the depth, A H, and either the width of the thread, A R, or the width of the groove, R C. In the figure, the width of the thread, A R, is taken equal to one-half of the pitch, that is, A R and R C are equal. Beginning at A, draw the helix A B C, and beginning at R draw the helix R M N, R N of course being equal to A C. Since the part between A and R is metal, forming the thread, there will be a line from A to R and from B to M, etc. Now, starting at point H vertically under A and at a distance from A equal to the depth of the thread, draw the helix H J V, and from S vertically under R draw helix S T W. Draw the lines S V, T N, etc. Here, as in the case of the V thread, the invisible lines must be drawn when making the drawing; but need not be inked.

Fig. 16 shows the construction of a double square thread. An explanation is not necessary, since the difference between this



LEFT-HAND THREAD.



RIGHT-HAND THREAD.

FIG. 14.

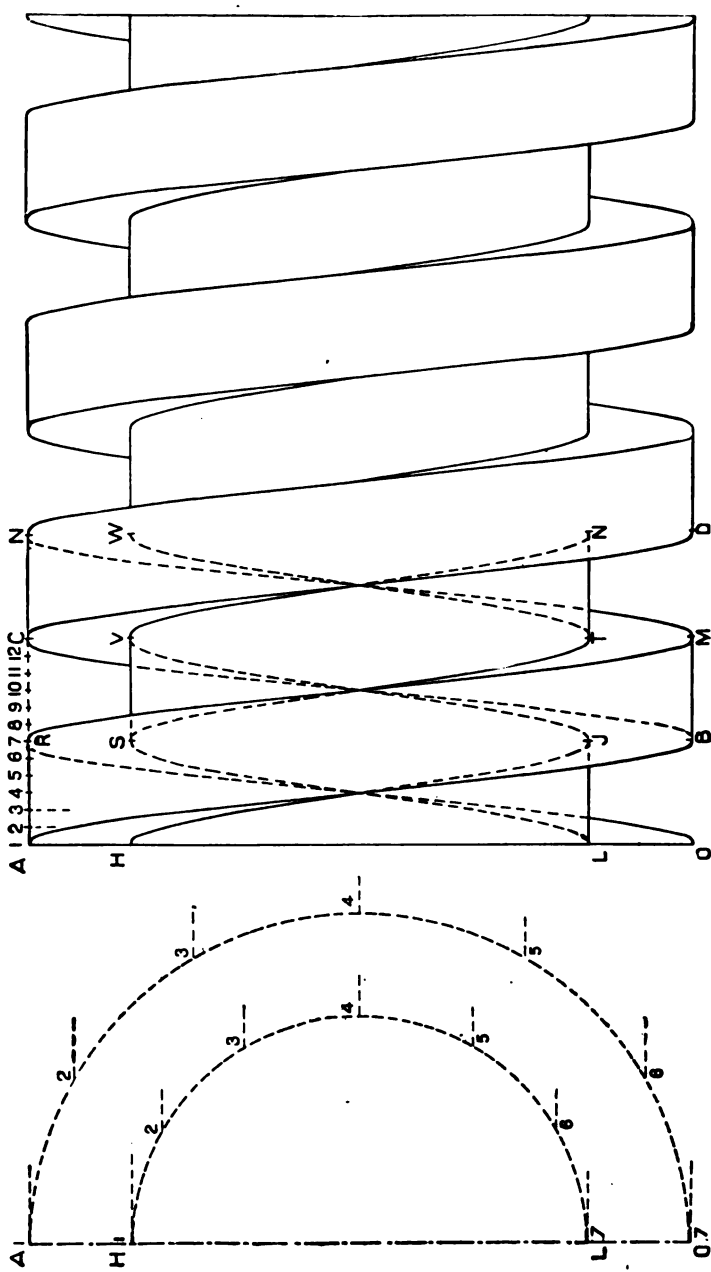


Fig. 15. Construction of Square Thread.

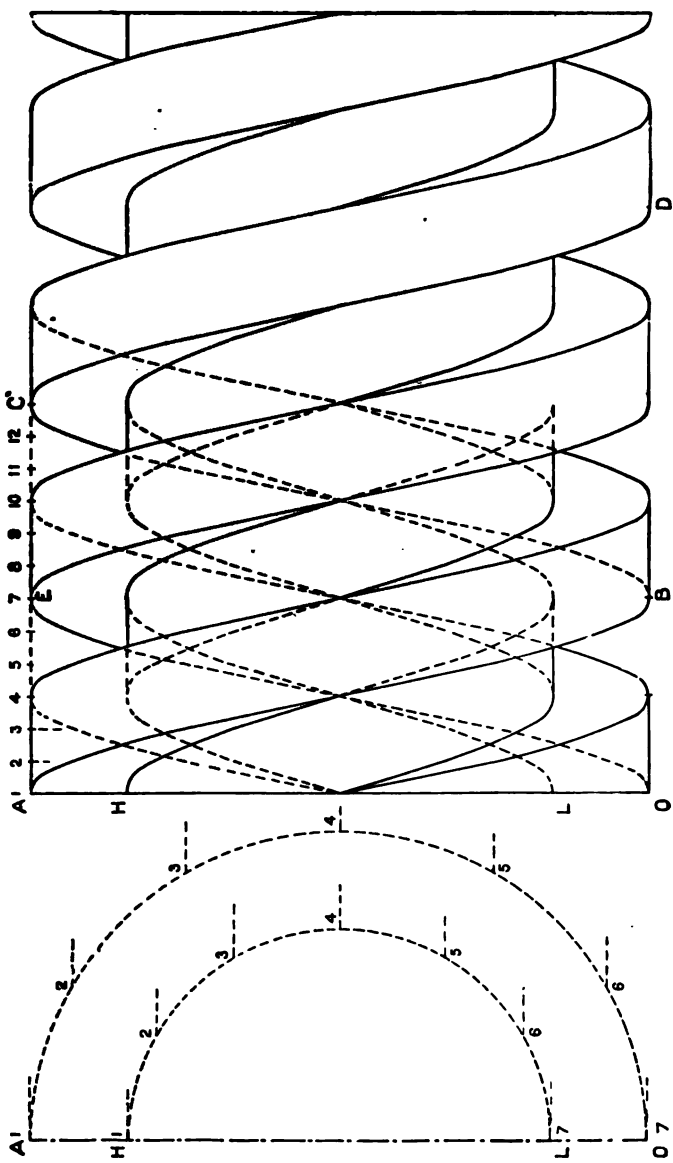


Fig. 16. Construction of Double Square Thread.

and the single square thread is practically the same as between the single and double V thread.

The V and square threads are the two fundamental forms of threads in use and all other forms are modifications of one or the other of these two. Figs. 17 to 20 show some of the more common modifications.

Figs. 17 and 18 show the two forms of the V thread which are commonly used in practice.

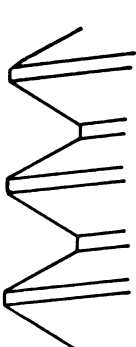


Fig. 17.



Fig. 18.



Fig. 19.

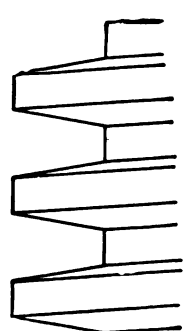


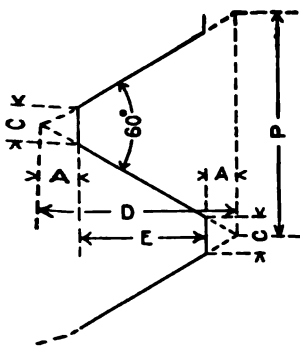
Fig. 20.

In Fig. 17 we have what is known as the Sellers or United States standard thread, an enlarged drawing of which is shown in Fig. 21. Referring to this figure, we see that the angle between the two sides of the thread is 60 degrees, so that if the thread came to a point at the top and bottom, as indicated by the dotted lines, the depth of the thread, D , would be about $\frac{87}{100}$ of the pitch, P . The sharp corners, however, are a disadvantage, since on the outside they are likely to be bruised, and give trouble in putting on the nut, and at the bottom of the groove they tend to weaken the bolt or screw. In order to avoid these sharp corners, the threads are flattened in the United States standard thread, as shown in Fig. 21, the amount of this flattening being such that the distance C is $\frac{1}{8}$ of the pitch, or, what amounts to the same thing, the distance A is $\frac{1}{8}$ of D . This gives a thread whose depth, E is $\frac{65}{100}$ of the pitch.

Fig. 18 illustrates what is known as the Whitworth standard thread, shown enlarged in Fig. 22. Here the angle between the

sides of the thread is 55 degrees, so that if the threads came to sharp corners, as shown by the dotted lines, the depth D would be $\frac{96}{1000}$ of the pitch. The top and bottom of the thread, instead of being flattened, are rounded off so that the distance A is $\frac{1}{8}$ of D , or the depth E is $\frac{64}{1000}$ of the pitch.

Fig. 19 shows the V thread as used on lag screws and other wood screws. Here the groove is much larger than the thread,



$$D = \frac{866}{1000} \text{ OF PITCH}$$

$$A = \frac{1}{8} \text{ OF } D.$$

Fig. 21.

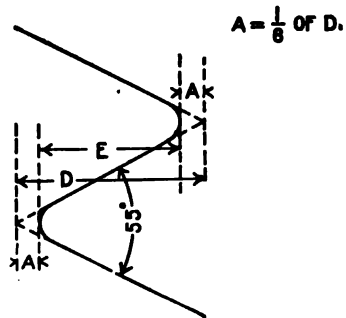


Fig. 22.

because the wood into which it is to screw is weaker than the iron of which the screw is made.

Fig. 20 shows a slightly modified form of square thread, the only difference between this and the square thread previously described being that the sides of the groove taper slightly.

Conventional Representations. The student should understand the drawing of the threads, as previously explained, and every draftsman should be able to draw the true projection of a thread if he should have occasion to do so. It is evident, however, that the process is somewhat long, and on a screw of small diameter and pitch it would be difficult to follow out the construction. To avoid this labor the construction shown in Figs. 23, 24 and 25 may be adopted, straight lines being substituted for the projections of the helix. Fig. 23 shows the conventional

representation of the plain single right-hand V thread, the true projection of which was shown in Fig. 12. To make the conventional drawing (Fig. 23) draw the parallel lines $A B$ and $C D$ at a distance apart equal to the outside diameter of the screw, and draw the line $A C$ perpendicular to these two lines. Along $A B$ lay off the distances $A E$, $E F$, etc., each equal to the pitch. Along $C D$ lay off $C H$ equal to $\frac{1}{2}$ the pitch, and from H lay off $H I$, $I J$, etc., equal to the pitch. Draw lines from A to H , E to I , etc. Now, if the depth of the thread $A S$ is known, draw the lines $S T$ and $U V$, and beginning at L , perpendicularly under a

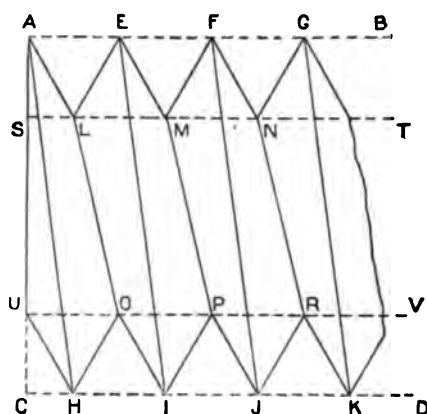


Fig. 23.

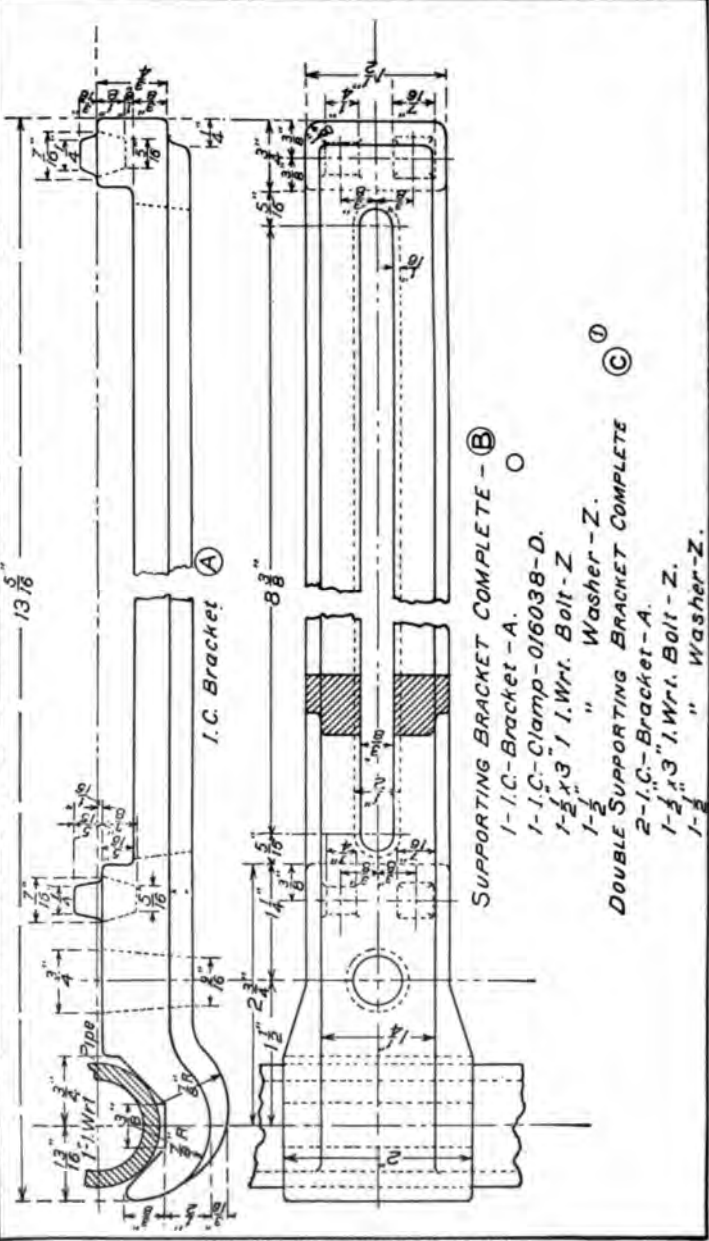
point halfway between A and E lay off $L M$, $M N$, etc., equal to the pitch. In like manner find the points O , P , R , etc., and draw the lines $L O$, $M P$, etc.; also $A L$, $L E$, $H V$, $H O$, etc. The dotted lines should be left out in the finished drawing, but are put in the figure to show the construction.

If, instead of knowing the depth $A S$, we know

the angle between $A L$ and $L E$, the depth can be found by drawing from A and E the two lines $A L$ and $E L$ in such a way that they would make the required angle with each other. To do this the lines $A L$ and $E L$ would each make an angle with the line $A B$ equal to 90 degrees minus $\frac{1}{2}$ the angle between $A L$ and $L E$.

Fig. 24 shows the corresponding construction for the United States standard thread. Draw the lines $A B$, $C D$ and $A C$ as in Fig. 23, and find the points E , F , G , H , I , J , K , etc., in the same way as in that case. Now draw the lines $S T$ and $U V$ so that $A S$ and $C U$ shall equal $\frac{.65}{160}$ of the pitch $A E$. On the line $A B$ lay off from A a distance, $A 1$, equal to $\frac{1}{16}$ of the pitch, and each side of E , F , G , H , etc., lay off $E 2$, $E 3$, etc., each equal to $\frac{1}{16}$ of the pitch. From the points thus found draw lines $1-4$, $2-5$, etc.,

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 Transformer Supporting Bracket for Switchboard Pipe Frame.



INSPECTED BY P.N. MOORE
 PASSED BY P.N. MOORE
 APPROVED BY P.N. MOORE

- SUPPORTING BRACKET COMPLETE - (B)
- 1- I.C.-Bracket - A.
 - 1- I.C.-Clamp - 016038-D.
 - 1- 2"x3" I.Wrt. Bolt - Z
 - 1- 2" Washer - Z.
- DOUBLE SUPPORTING BRACKET COMPLETE (C)
- 2- I.C.-Bracket - A.
 - 1- 2"x3" I.Wrt. Bolt - Z.
 - 1- 2" Washer - Z.

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making an angle of 60 degrees with A B. The rest of the drawing is completed as shown by drawing in full lines those parts of the lines A B, C D, S T and U V intercepted between 1-4 and 2-5, etc.

Fig. 25 shows the conventional representation of a square thread, and is drawn in exactly the same way as the true projection shown in Fig. 15, except that straight lines are used instead of curves.

Square threads are almost always represented as in Fig. 25, and V threads of coarse pitch and large diameter are shown as in Fig. 23 or 24, but

when we have a screw of small diameter and fine pitch, such a method would become difficult, so that we most frequently find V threads represented as in Fig. 26. The lines A B and C D are drawn full, their distance apart being equal to the outside



Fig. 25.

and heavier lines are drawn, the distance from A B and C D to the ends of the heavy lines being a little less than A F. To have these lines of uniform length it is well to draw light pencil lines, as a guide for stopping the heavy lines, these guide lines being erased when the drawing is finished.

Fig. 27 shows the same method of representing a double

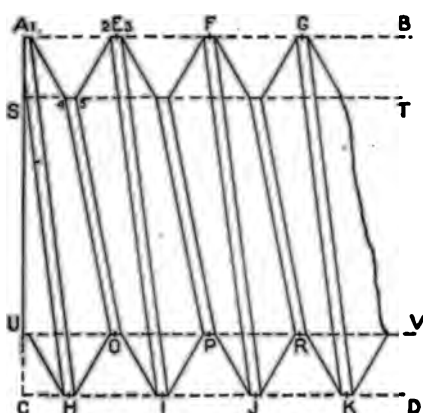


Fig. 24.

diameter of the screw. A F, F H, etc., are laid off to represent the pitch (though in small screws it is frequently made larger than the actual pitch). For a single thread, C E is equal to $\frac{1}{2}$ of A F, or, in other words, E is perpendicularly opposite a point halfway between A and F. A E is drawn, and F G, H J, etc., drawn parallel to A E. Halfway between the lines A E and F G, the shorter

thread. The only difference between this and Fig. 26 is that in Fig. 27 C E is equal to A F; that is, E is perpendicularly opposite F.

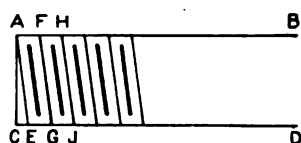


Fig. 26.

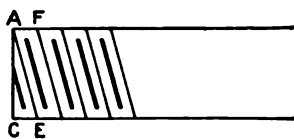


Fig. 27.

CAMS.

A cam is a piece of mechanism which, by means of its rotation about a fixed axis, imparts a back and forth motion to another piece in contact with it. There are several forms of cams which we shall consider, but before beginning the study of the cams and how to draw them it will be necessary for us to understand something of the different kinds of motion a piece may have, because a cam must be designed to give the piece the kind of motion desired.

Kinds of Motion. If we classify the kinds of motion which we meet with in machinery according to the rate of motion, or velocity, the three most common kinds are *uniform motion*, *harmonic motion* and *uniformly accelerated and uniformly retarded motion*. These will be more readily understood after we have considered one or two illustrations.

Uniform Motion. Suppose a railway train to travel ten miles in twenty minutes, the speed of the train being the same during each minute; it would travel $\frac{1}{2}$ mile in each minute, and would be said to have a *uniform* speed, or *uniform* velocity of $\frac{1}{2}$ mile per minute. Under such conditions the train would be moving at the full speed of $\frac{1}{2}$ mile per minute both at the beginning and at the end of the ten miles. If, however, it had exactly ten miles to travel and exactly twenty minutes to do it in, and must be at full stop at the beginning and at the end of the given time, it could not take up its full speed in an instant nor lose it in an instant, but must start gradually and stop gradually, and therefore during the first part and the last part of the time would be moving at a speed slower than $\frac{1}{2}$ mile per minute, and must go faster than $\frac{1}{2}$ mile per minute during the middle part of the run to make up for

the time lost in starting or stopping, or, in other words, the motion would not be uniform. The more suddenly the train starts and stops, the more nearly uniform the motion may be, but the greater the shock when starting and stopping. Let us take another example on a smaller scale. Suppose we have some sort of a piece to be moved one foot across a machine in ten seconds, if the motion is to be uniform, the piece would have a velocity of $\frac{1}{10}$ foot per second. If the piece is light and the mechanism which does the moving is sufficiently powerful, the piece may be made to start and stop almost instantly and consequently may have what is practically uniform motion. It is evident, however, that the shock at starting and at stopping would be considerable.

Varying Motion. If the mechanism which moves the piece is so designed as to start and stop it gradually, the shock will be avoided. The character of this gradual increase and decrease of speed might be one of several kinds, but what would most likely be met in practice would be either a gradual increase of speed at the start, until full speed is attained, then a uniform full speed during the main part of the stroke, and finally a gradual decrease of speed to a full stop at the end of the stroke; or the speed would increase during the entire first half of the stroke, and decrease during the entire last half, the motion at no time being uniform. The first condition is most likely to be used where the piece is doing work during the stroke, as, for instance, the cutting stroke of a tool, and the second condition is used where it is desired to get the piece across quickly without regard to the character of the motion as long as it is without shock. The character of the motion usually employed in this case is either what is known as *harmonic motion* or *uniformly accelerated and retarded motion*, and we will now study these.

Harmonic Motion. In Fig. 28 let the semicircle A B D represent the path along which a piece moves with a uniform velocity. Now, if we have another piece moving along the diameter A D, starting from A at the same time that the first piece does, and moving at such a speed that a perpendicular let fall from any position of the first piece to the line A D will strike where the second piece is,—that is, when the first piece is at C the second piece is at E; when the first piece is at B the second piece is at O,

and so on,—then the piece which travels across the line A D is said to have *harmonic* motion, and it is evident that it moves slowly at first, increases to a maximum speed at the center, and decreases towards the end.

Uniformly Accelerated and Retarded Motion. A piece which has uniformly accelerated and uniformly retarded motion travels at such a speed that it will move through one unit of space in the first unit of time, three the second, five the third, seven the fourth, nine the fifth, etc., to the middle of its stroke, then decreases at the same rate to the end of the stroke. For example, if a piece is to move with uniformly accelerated and retarded motion one foot in ten seconds, it will move $\frac{1}{50}$ foot the first second, $\frac{3}{50}$ the

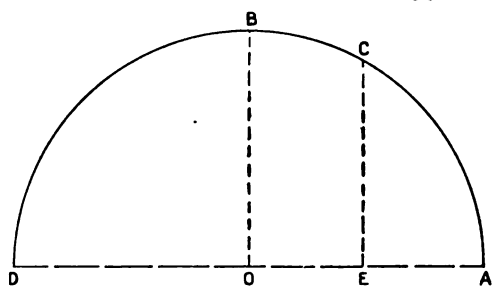


Fig. 28.

second, $\frac{5}{50}$ the third, $\frac{7}{50}$ the fourth, $\frac{9}{50}$ the fifth, when it will have traveled $\frac{1}{50} + \frac{3}{50} + \frac{5}{50} + \frac{7}{50} + \frac{9}{50} = \frac{25}{50}$ or $\frac{1}{2}$ the whole foot in five seconds, or $\frac{1}{2}$ the whole time, the speed increasing all the time; at the end of the fifth second,

or in other words, when half the distance has been traveled, it begins to slow down, and travels $\frac{9}{50}$ the sixth second, $\frac{7}{50}$ the seventh, $\frac{5}{50}$ the eighth, $\frac{3}{50}$ the ninth, and $\frac{1}{50}$ the tenth. The rate at which the velocity increases during the first half of the time is the same as that at which the velocity of a weight will increase if dropped from a height, and the rate at which the velocity decreases during the last half of the time is the same as that at which the velocity of a ball will decrease if thrown straight up into the air. Uniformly accelerated or uniformly retarded motion is therefore often spoken of as *gravity* motion.

One of the most common means of obtaining the kinds of motion just described is by cams, although these are not often used for motions greater than a few inches.

Kinds of Cams. Cams may be divided into two general classes, *plate cams* and *cylindrical cams*. Either one of these may be designed for uniform motion, for harmonic motion, for

avity motion, or for a combination of two or even of all three.

Plate Cams. Fig. 29 shows the front and side views of a plate cam designed to raise the sliding piece *P* a distance *A e*; the lowest position of *P* being when its point is at *A*, and the highest position being when its point is at *e*, as indicated by the dotted lines. The cam turns right-handed, as shown by the arrow, and raises *P* with uniform motion from *A* to *e* while turning through

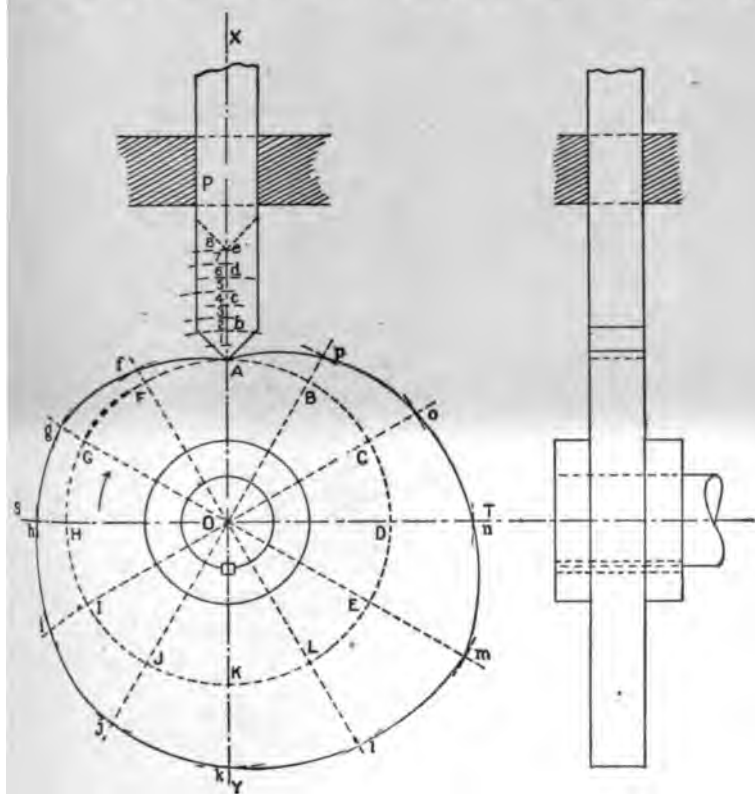


Fig. 29.

$\frac{1}{3}$ of a revolution, then lowers *P* with uniform motion to its original position while turning through the remaining $\frac{1}{3}$ revolution.

To design such a cam, start with the point *O* (the center of the shaft on which the cam is fixed); through *O* draw the center line *XY*, and locate point *A* by measuring up from *O* the distance *OA*, which must be known; from *A* lay off *A e*, which must

also be known; with O as a center and radius $O A$ draw the circle $A H K D$; on this circle find a point E such that arc $A H E$ shall be to arc $A C E$ as the time allowed to raise P is to the time allowed to lower P . In this case, since P is to rise in $\frac{2}{3}$ of a revolution of the cam, and fall in $\frac{1}{3}$ of a revolution, the time allowed for it to rise is twice the time allowed for it to fall, and therefore the arc $A H E$ is twice the arc $A C E$, or, in other words, the arc $A H E$ is $\frac{2}{3}$ of the whole circumference, and $A C E$ is $\frac{1}{3}$ of the circumference. If the cam were to turn left-handed instead of right-handed, the arc $A C E$ would be $\frac{2}{3}$ of the circumference and $A H E$ $\frac{1}{3}$. Now since the motion is to be uniform, divide line $A e$ into any number of *equal* parts (eight are used in the figure) and divide the arc $A H E$ into the same number of equal parts; draw the radial lines $O F$, $O G$, etc., as shown; with O as a center and radius $O 1$ draw an arc cutting $O F$ at f ; with O as a center and radius $O 2$ cut $O G$ at g , and so on around to m . A smooth curve drawn through the points A, f, g, h , etc., around to m , will form the outline of that portion of the cam which raises P . Now it is evident that when the cam has turned through the angle $A O F$ the line $O F$ will coincide with the center line $X Y$, and the point f will coincide with point 1, and therefore the cam will have pushed the point of P from A to 1. In the same way, when the cam has turned through angle $A O G$, point g will coincide with 2, and when cam has made $\frac{2}{3}$ of a revolution m will coincide with 8 (which is the same as e), and P will have been raised the required amount.

The outline of the rest of the cam is found by dividing arc $A C E$ into any number of equal parts, and making a new division of $A e$ into the same number of equal parts (ed, dc , etc.). Points n, o and p are found in the same way as f, g , etc., and a smooth curve drawn through them.

Fig. 30 shows a plate cam similar to that shown in Fig. 29, except that in Fig. 30 the piece P is raised from A to e during $\frac{1}{2}$ a revolution of the cam, and lowered during the other $\frac{1}{2}$ revolution; that is, the time allowed for raising P is the same as the time allowed for lowering it. The motion is uniform in both raising and lowering. The method of drawing this cam is similar to that explained in Fig. 29, except that $\frac{1}{2}$ the circle $A H$

K D is divided into the same number of equal parts as the line A e instead of $\frac{2}{3}$ as before, k now being the point farthest from the center instead of m as in the previous case. This form of cam is called a *Heart Cam*.

Fig. 31 shows another cam, which is similar to that of Fig. 29. It will be noticed, however, that in Fig. 29 the line in

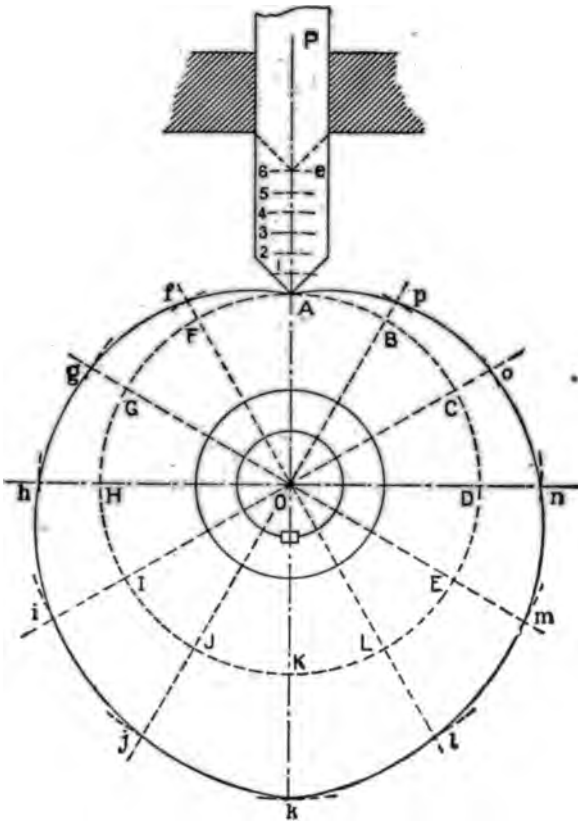


Fig. 30.

which A travels coincides with the center line, X Y, or, in other words, the line of motion of point A passes through the center of the cam. In Fig. 31 the path of A does not pass through the center of the cam, but lies in the line V W, which passes a distance R to one side of the center O. The cam shown in the figure is designed to raise P a distance A e in $\frac{2}{3}$ of a revolution,

and lower it in the remaining $\frac{1}{3}$, just as in Fig. 29, the motion being uniform. To design the cam, locate center O and draw the center lines $X Y$ and $S T$ at right angles with each other. On $S T$ measure from O a distance equal to R , which must be known, thus getting the point a ; through a draw $V W$ parallel

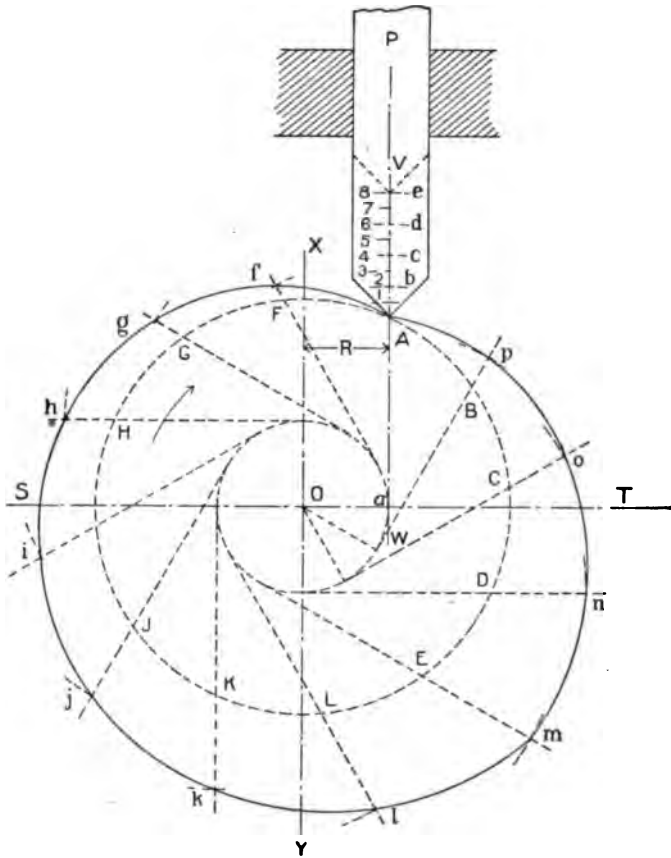


Fig. 31.

to $X Y$. Locate A and e on this line, the distances $A a$ and $A e$ being known. Through A draw a circle with O as a center; on this circle locate point E so that arc $A H E$ shall be to arc $A C E$ as time required to raise P is to time required to lower it; in this case as $\frac{2}{3}$ is to $\frac{1}{3}$, or, in other words, arc $A H E$ is $\frac{2}{3}$ of the circumference. Divide $A e$ into any number of equal parts, and divide

arc A H E into the same number of equal parts. With O as a center and radius O a, draw a circle tangent to V W, and through the points of division F, G, H, etc.; on the large circle draw lines tangent to the smaller circle. With O as a center draw an arc through point 1, cutting line through F at *f*; points *g*, *h*, etc., are found in the same way by drawing arcs through 2, 3, etc. A smooth curve drawn through these points around to *m* gives the outline of that part of the cam which raises the point of P from A to *e*. The curve through *n*, *o*, *p*, which lowers P, is found in the same way. It will be noticed that the only differ-

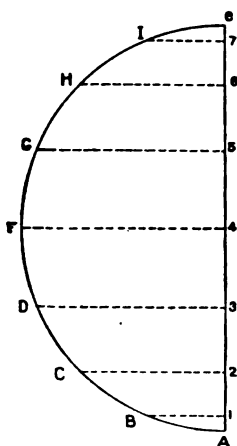


Fig. 32.

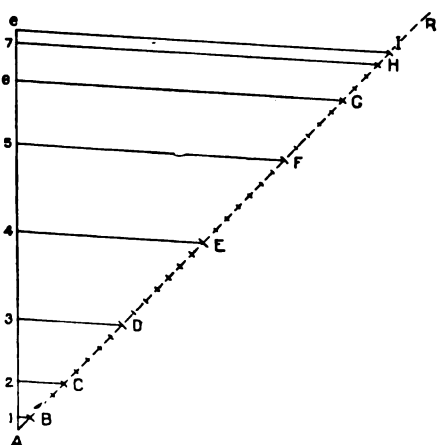


Fig. 33.

ence between the method of laying out this cam and that in Fig. 29 is that the lines on which points *f*, *g*, *h*, etc., are found are drawn tangent to the small circle instead of to the center. The hub and bore for shaft are omitted on this drawing to avoid confusing the lines.

If, in Fig. 29, it had been required to raise and lower P with harmonic motion instead of uniform motion, the only difference in construction would have been in the dividing up of the line A *e*. The divisions A F, F G, etc., on the circle, would be the same as for uniform motion; that is, they would be equal to each other. The divisions A-1, 1-2, etc., on line A *e*, instead of being equal would be found as shown in Fig. 32. On the line A *e* as a diam-

eter, draw a semicircle, and divide this semicircle into as many equal parts as we divide the arc A H E in Fig. 29. From the points B, C, D, etc. (Fig. 32), draw perpendiculars to line A e, cutting it at points 1, 2, 3, etc. These are the points which we would use for finding points *f*, *g*, *h*, etc., on the cam outline (Fig. 29). Fig. 32 is drawn to a larger scale than Fig. 29.

Fig. 33 shows how to divide the line A e, if the motion were to be uniformly accelerated and uniformly retarded. Since the line A e is to be divided into the same number of parts as the arc A H E, it will be divided into eight parts in this case. Now if the motion which the cam is to give to the piece P is to be uniformly accelerated and retarded, the line A e must be divided up in such a way that the distance from 1 to 2 is three times the distance from A to 1; the distance from 2 to 3 is five times the distance from A to 1; 3 to 4 is seven times A to 1; 4 to 5 is seven times A to 1; 5 to 6 is five times A to 1; 6 to 7 is three times A to 1; and 7 to e is equal to A to 1. Therefore the whole line A e is $1 + 3 + 5 + 7 + 7 + 5 + 3 + 1$, or thirty-two times the distance from A to 1, or, in other words, A-1 is $\frac{1}{32}$ of the whole line A e, 1-2 is $\frac{3}{32}$ of A e, and so on. To divide up A e so that the divisions may bear the above relation to each other, draw the line A R at any convenient angle, and choosing any convenient distance as a unit, mark it off on this line thirty-two times, beginning at A; from I, the last of these dividing points, draw a line to e; next find the points B, C, D, etc., as follows: B is the first division from A, C the third from B, D the fifth from C, E the seventh from D, F the seventh from E, G the fifth from F, H the third from G; through the points H, G, F, etc., draw lines parallel to I e, cutting line A e at 7, 6, 5, 4, etc.; then these points will be the required points of division for the line A e.

Fig. 34 shows a cam designed to raise P with uniformly accelerated and retarded motion, while the cam is turning right-handed through $\frac{1}{3}$ of a revolution; then P is to be held fixed in its raised position while the cam turns through the second $\frac{1}{3}$ revolution, and to be lowered with harmonic motion during the last $\frac{1}{3}$ revolution. The construction involves the methods already described. The arcs A F M, M N V and V E A are each $\frac{1}{3}$ of the

circumference. The dividing of the line $A e$ for uniformly accelerated and retarded motion is shown at the left of $A e$, giving points 1, 2, 3, etc., which are swung on to the lines $O G$, $O H$, etc., and thus locating points g , h , etc., as in the previous cams.

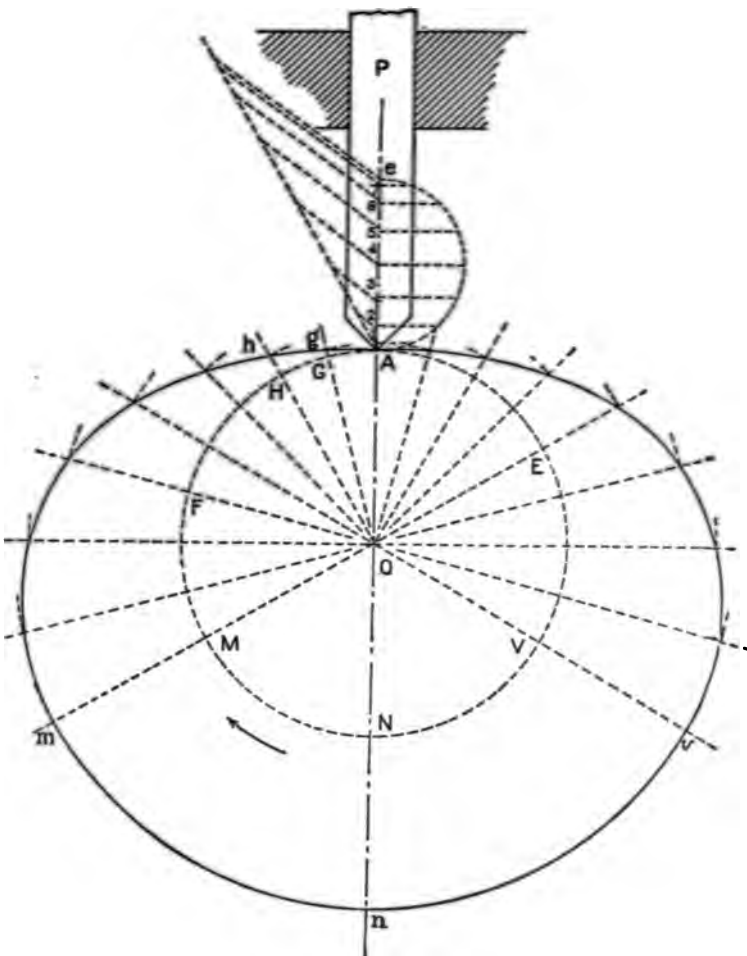


Fig. 34.

When the cam has turned through the angle $A O M$, the line $O m$ coincides with line $O e$, point m being at e , and the point of P will be raised to e . Now the point of P is to remain at e while the cam turns through the next $\frac{1}{3}$ revolution, that is, while it

turns through the angle $M O V$ and therefore that part of the outline of the cam from m to v is an arc of a circle drawn with O as a center. The dividing of $A e$ for the harmonic motion for lowering P is shown at the right of $A e$, and the points on the cam outline are found in the same way as before.

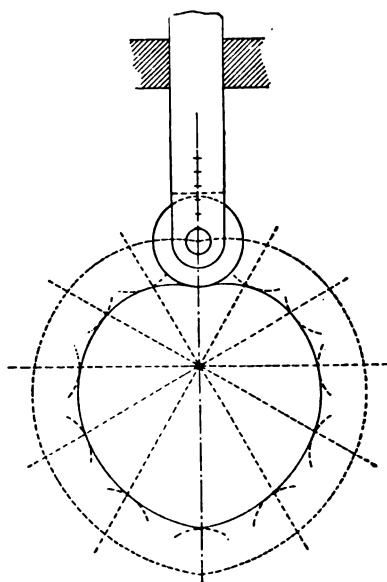


Fig. 35.

The cams which we have been considering all act on the comparatively sharp end of the piece P , and it is evident that, as the cam turns, its surface must slide on P , causing friction and rapid wearing. If, however, the end of P is provided with a roller which bears on the surface of the cam, the sliding and consequent wearing are avoided. Fig. 35 illustrates this, and shows how to lay out the cam. The cam here shown is to give the same kind and amount of motion to the follower P as the cam shown in Fig. 30. We first find the curve for the cam outline, if it acted on a pointed

piece, as in Fig. 30, the center of the roller being at the place where the point of P is in Fig. 30. This curve is shown dotted in Fig. 35, and is exactly the same curve as the outline of the cam in Fig. 30. Now, with a radius equal to the radius of the roller which is to be used, and with centers at any number of points around the curve, draw arcs as shown. A smooth curve drawn *tangent* to these arcs will be the outline of the cam to act on the roller.

Cylindrical Cams.* A plate cam, as we have seen, can be designed to give almost any kind of motion in a plane at right angles to the axis of the shaft on which it is located, but cannot give motion in a line parallel to the axis of the shaft. If, however, we put a cylinder on the shaft with a groove cut in it, the

* The subject "Cylindrical Cams" is optional.

shape of the groove may be made such as to give to a piece inserted in it almost any desired motion in a line parallel to the axis of the shaft. Such a cam is called a cylindrical cam, and is shown in Fig. 36, which, together with Figs. 37 and 38, shows the method of designing. This cam is designed to turn in the direction indicated by the arrow, and in so doing is to move a roller a distance A to the right with harmonic motion while turning $\frac{1}{4}$ revolution, to allow the roller to remain stationary during the next $\frac{1}{4}$ revolution, to move it back to its original position with uniformly accelerated and retarded motion during the third $\frac{1}{4}$

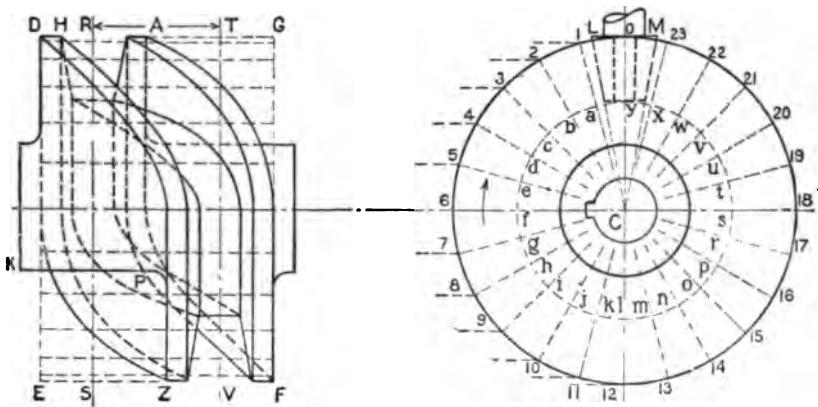


Fig. 36.

revolution, and to keep it stationary during the last $\frac{1}{4}$ revolution.

The roller is shown in the end view of the cam, and is of a diameter $L M$ at its outer end, and of a length $O y$; it is made tapering, being the frustum of a cone whose apex is at the center of the cam. The depth of the groove is made exactly equal to the length of the roller, $O y$, and the width of the groove is made equal to the diameter of the roller. The arrangement might be a little different in practice, but this will show the method of designing.

The length of the cylinder which forms the cam is $D G$, which is equal to A (the distance between the two extreme positions of the center of the roller) plus twice the radius of the

roller, plus twice D H (the thickness of metal allowed between the groove and the outside). In the figure the hub is allowed to project a little at each end.

To lay out the cam: Draw the two views of the cylinder, the side view being the rectangle D E F G, and the end view being the circle 0-6-18. We will start with the point 0. Since the roller is to move through distance A while the cam turns $\frac{1}{4}$ revolution, we lay off from 0 the arc 0-3-6 equal to $\frac{1}{4}$ the circumference; and the groove in this part of the cylinder must be such that when the cam has turned in the direction shown by the arrow until point 6 coincides with 0, the axis of the roller will have moved along in harmonic motion from a position coincident with center line R S (side view) to a position coincident with center line T V. The axis of the roller is to remain coincident with T V during the next $\frac{1}{4}$ revolution of the cam, that is, until point 12 comes to 0, and consequently the groove in this part of the cam goes straight around, the projection of its center line coinciding with T V. The roller is to be moved back until its axis coincides with R S with uniformly accelerated and retarded motion, while the next $\frac{1}{4}$ revolution is made, or until point 18 comes to 0, and the groove in this $\frac{1}{4}$ of the cam must be made such as will give that motion. The groove in the remaining $\frac{1}{4}$ of the circumference is again to be such as to keep the axis of the roller stationary, or, in other words, is to have the projection of its center line coincident with R S.

Now, in order to draw the projection of the groove in the side view, it will be necessary to make a development of the surface of the cylinder, using the same principles that were involved in the development of cylinders in Part III. Fig. 37 shows the development, and we will now consider in detail the method of making and using it. In Fig. 36 divide each of the arcs 0-6, 6-12, 12-18, 18-0 into any number of equal parts. In making the division it is more convenient to make the spaces into which these arcs are divided equal for all the arcs—that is, 1-2, etc. = 6-7, etc. = 12-13, etc. = 18-19, etc. On the side view of the cylinder (same figure) draw the elements corresponding to those points of division. Next draw the rectangle D E D' G' F G (Fig. 37), the length of the side D E D' being equal to the cir-

cumference of the circle 0-6-18 (Fig. 36), and the length of the side G D being the same as the line G D in Fig. 36. On

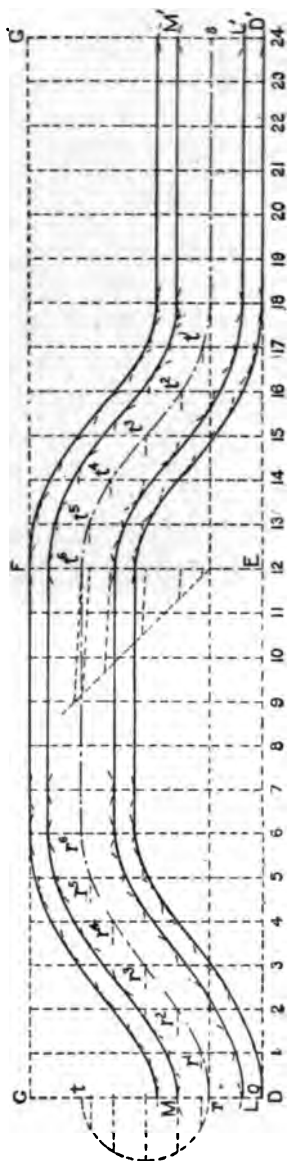
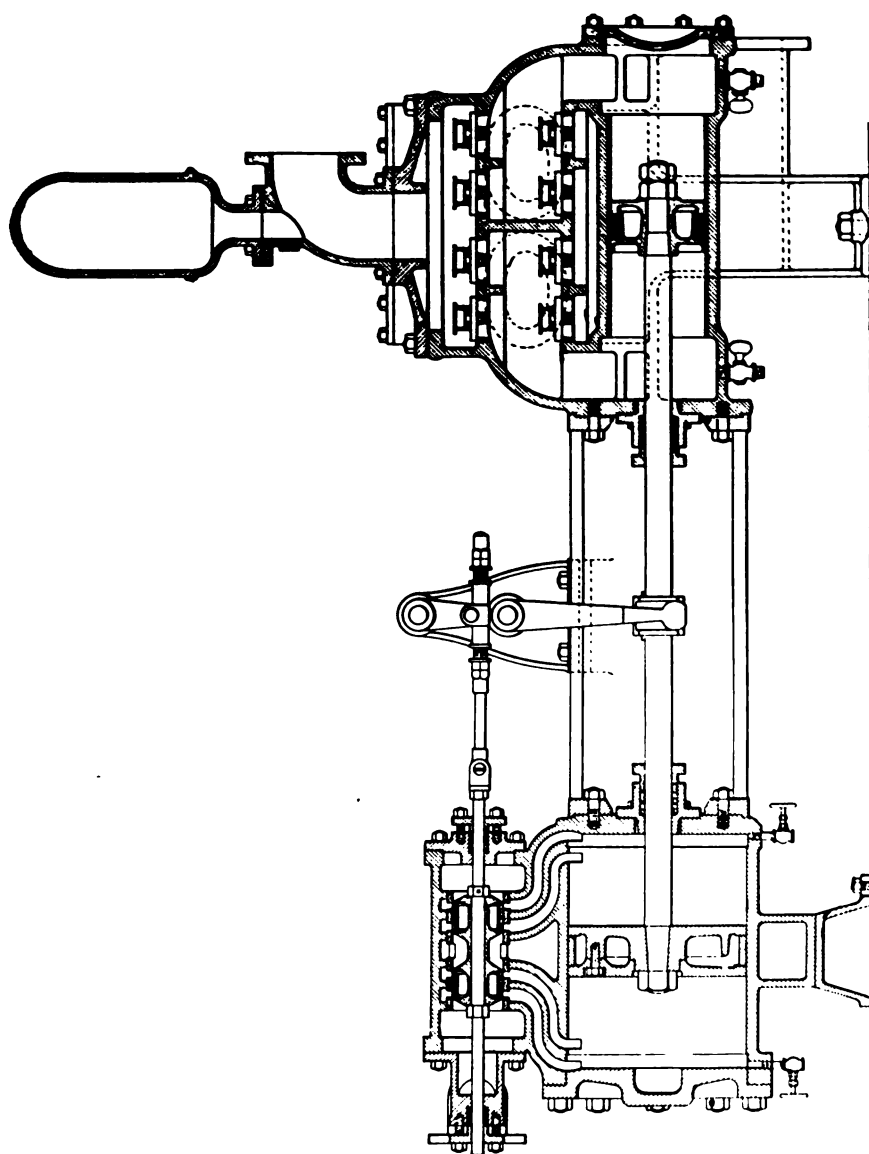


Fig. 37.

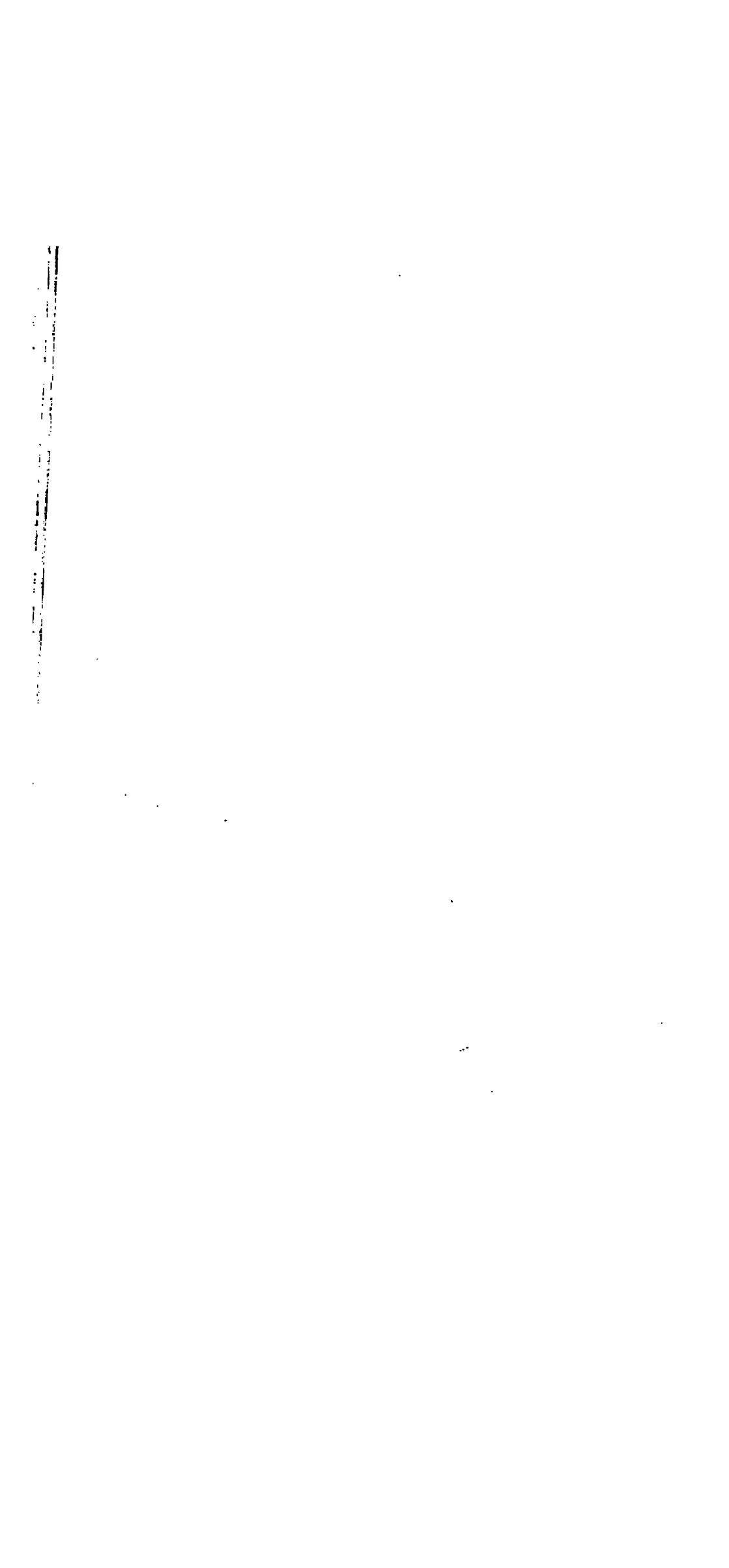
D E D' locate points 6, 12, 18, by making distances D-6, 6-12, 12-18, 18-D' equal respectively to arcs 0-6, 6-12, 12-18, 18-0, in Fig. 36. Divide each of the distances D-6, 6-12, etc., into the same number of equal parts as there are divisions in the corresponding arcs in Fig. 36, and at these points of division, which are numbered 1, 2, 3, etc., to correspond with the points in Fig. 36, erect perpendiculars as shown. On D G (Fig. 37) locate point r , making D r equal to the distance from D to line R S (Fig. 36), and draw line $r s$ parallel to D D'.

From r lay off $r t$ equal to A, and divide $r t$ for harmonic motion as shown, making the number of divisions the same as those between D and 6. From the first point of division project across to the perpendicular which was erected at 1, from the second point of division to the perpendicular which was erected at 2, etc., thus getting the points r^1, r^2, r^3, r^4 , etc., to r^6 . Through these points draw a smooth curve, as shown in dot and dash. The perpendicular distance from any point on this line, as r^3 , to the line $r s$, represents the distance that the axis of the roller has moved to the right of the center line R S, while the cam has turned

through the angle corresponding [through angle 0 C 3 (Fig. 36), if we consider the point r^3]. Since that part of the



CROSS SECTION OF DOUBLE ACTING STEAM PUMP.



diameter is the diameter of the larger one less twice the depth of the groove shown by the dotted circle in the end view of Fig. 36. The development is shown in Fig. 38, and is done in a manner exactly similar to that employed in Fig. 37. The method of getting the corresponding curves in the side view of Fig. 36 is also the same as for the curves on the outer cylinder.

We would now have a cam which would appear as in Fig. 39; but it is evident that there is a good deal of unnecessary metal, so that instead of making it a complete cylinder, the stock is usually cut away, as shown by the outer curves in Fig. 36, so that the distance from the center of the groove to the outside of the metal is everywhere equal to the distance from D to line R S. The projections of these outer edges of the metal are found by first making the development in Fig. 37, obtaining the upper and lower of the curves by striking arcs from the center curve with a radius equal to distance from D to R S (Fig. 36), and drawing the curves tangent to these arcs. The curves are transferred to the side view of Fig. 36 in the same way that the rest of the curves were. The hub is now drawn, extending as far beyond the rest of the cam as is desired, the contour of the hub (as K P) being visible to a point perpendicularly opposite where the outside edge of the cam strikes the contour of the cam (point Z for line K P).

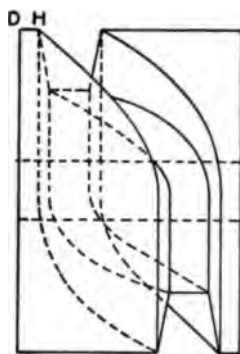


Fig. 39.

BELTING.

The word shaft, in connection with machinery, is a name applied to a bar, either hollow or solid, usually of circular cross-section (in common language, round), supported in suitable bearings so as to be free to turn, and intended to receive a motion of rotation from some source of power, and to transmit the motion to some other body, either another shaft or some piece of machinery. The number of times a shaft turns in a unit of time is

called the speed of the shaft, and is usually stated as number of turns in a minute, or revolutions per minute, which is abbreviated to R. P. M. ; this abbreviation will be used in what is to follow. When it is desired to drive one shaft from another at some distance from it, the connection is commonly made by placing on each shaft a pulley or wheel, and over these pulleys stretching a band or belt, as it is called, made of leather, rubber, canvas or some similar material. The pulleys are fastened to the shaft, so that a shaft and its pulley turn together, and the belt is stretched over the pulleys tight enough so that the friction be-

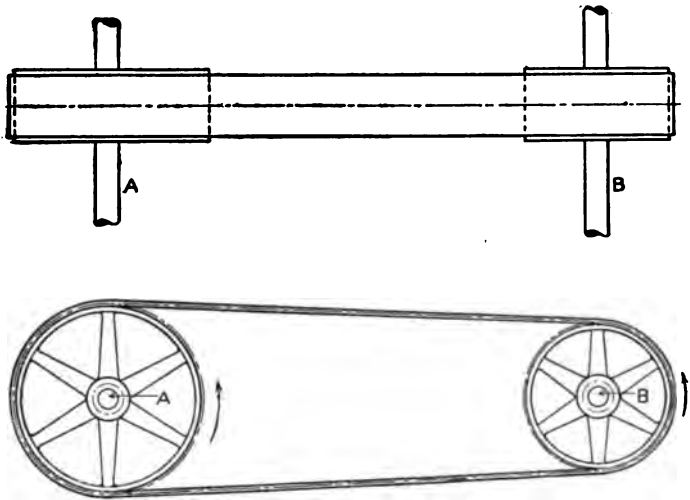


Fig. 40.

tween the belt and the surface of the pulleys is sufficient to make the linear speed of the belt practically the same as the linear speed of the circumference of the pulleys. The shafts which are connected by a belt may be parallel or nonparallel.

The methods of laying out the locations of pulleys and belts for the various cases which are commonly met with will now be considered. Before doing this, however, it will be necessary to consider a few general definitions and a few of the principles which govern belting.

Fig. 40 is an elevation and a plan of two shafts, A and B, which are connected by a belt. The *pitch line* of the belt is an

imaginary line exactly in the center of the belt, both as regards thickness and width. The pitch line of each pulley is a circle drawn around the center of the pulley, with a radius equal to the radius of the pulley plus one-half the thickness of the belt. The pitch line of the pulley, therefore, coincides with the pitch line of that portion of the belt which is in contact with the pulley. The pitch lines of both the belt and the pulleys are shown in the figure by dot and dash lines. The diameter of this pitch circle of the pulley is called the effective diameter of the pulley, and should be used in place of the real diameter in all calculations and drawings for the location of pulleys, if such calculations

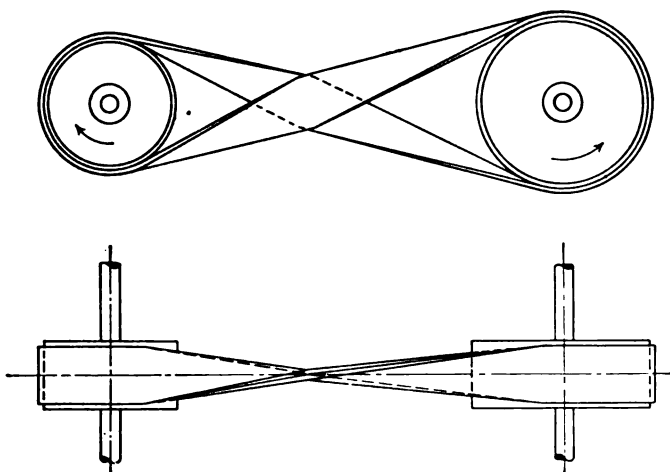


Fig. 41.

and drawings are required to be absolutely accurate. The thickness of the belt, however, is almost always small compared with the diameter of the pulley, so that the error introduced by neglecting to make allowance for this thickness is so small as to be almost unnoticeable. It is generally safe to use the real diameter of the pulley instead of the diameter of its pitch circle, and this will be done in our discussion of the subject.

Parallel Shafts. Open and Crossed Belts. The belt shown in Fig. 40 is what is known as an open belt, and two shafts connected by such a belt will both revolve in the same direction. Fig. 41 shows a crossed belt, which causes the driven shaft to

turn in the opposite direction from the driving shaft. The shafts in Fig. 40 and Fig. 41 are parallel to each other.

Shafts not Parallel. It very often happens that two shafts which are not parallel are to be connected by a belt, and this can always be done, whatever the position of the shafts with relation to each other, provided the pulleys are so located as to conform to one fundamental principle which governs the running of all belts. This principle may be stated as follows: The point where the center line of a belt leaves a pulley must lie in the plane which contains the pitch line of the pulley which receives the belt. Another way of stating this principle is: The center of a belt must be delivered into the center plane of the pulley to which it is running. This law is of great importance, as it applies to belts however they are bent or twisted, and the student should understand it clearly and have it fixed firmly in mind. From the study of geometry we learn that a plane is a perfectly flat surface, without thickness, and is supposed to extend indefinitely. The best example we can get of a plane is a thin, perfectly flat sheet of paper. The size of the paper may be increased indefinitely in all directions, but as long as the paper remains perfectly flat any two lines drawn on it will be in the same plane. So when we say that a certain point A on the surface of a pulley lies in the center plane of another pulley, we mean that if an imaginary flat surface is passed through the center of the second pulley, perpendicular to the shaft, and the flat surface is extended far enough, it will pass through the point A on the first pulley. This will be seen by referring to Fig. 42, which is a plan and two elevations of a belt connecting two shafts at right angles to each other, one shaft being above the other. The pulleys are arranged to turn in the directions indicated by the arrows. In the left-hand elevation it will be seen that the center line of that part of the belt which is moving downward leaves the upper pulley at the point A. The line X Y is the edge view (or trace) of the plane which passes through the center of the lower pulley, and in order that the belt may stay on the lower pulley, the lower pulley must be so located on its shaft that this line X Y shall contain point A. It will be noticed that the part of the belt which is moving upwards is drawn off the lower pulley at a considerable angle side-

wise; but this is allowable, for a belt leaving a pulley may be drawn out of the center plane of the pulley. Now, referring to the right-hand elevation, we see that the upward-moving part of the belt leaves the lower pulley at B; S T is the trace of the center plane of the upper pulley, and this pulley must be so located on its shaft that S T shall contain the point B.

The detail for making the drawing for this kind of a belt will be considered a little later, under the subject of quarter-turn belts, the brief explanation at this point being given to make clear what is meant by the principle of delivering a belt into the plane of the receiving pulley.

Quarter-turn Belt. A belt arranged to drive two shafts which are at right angles with each other, as shown in Fig. 42, is called a quarter-turn belt. There are various other methods of arranging the belt be-

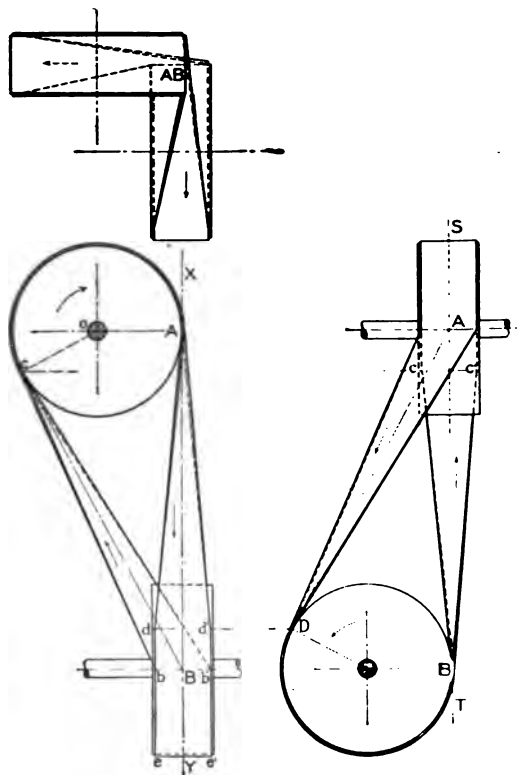


Fig. 42.

sides the one shown in Fig. 42, but as this is the simplest and easiest to understand we will study it first. With this arrangement the shafts must always turn in the same direction, for if the direction of rotation is reversed, neither pulley will deliver the belt into the center plane of the other pulley, and consequently the belt will not remain on the pulleys.

To draw the pulleys in their proper locations, having given

the location of the shafts with relation to each other, the direction in which each shaft is to turn, and the sizes of the two pulleys, proceed as follows : Draw first the two views of each shaft at the given distance apart, and put on the arrows to indicate the direction of rotation. Start with either pulley, let us say the upper one, and draw that view in which it appears as a circle, which in this case will be the left-hand view. Draw line X Y tangent to the circumference of this pulley at point A on the side which is turning downwards, A being on a horizontal line drawn through the center of the shaft. The point where X Y intersects the center line of the lower shaft will be the center of the other pulley, which will appear in this view as a rectangle of a length equal to the diameter of the pulley, and width equal to the width of the face of the pulley. Now draw the other view of the lower pulley, which will be a circle, and draw the line S T tangent to the circumference of this pulley at the point B, on the side which is turning upwards. The point of intersection of S T and the center line of the upper shaft will be the center of the rectangle which represents the side view of the upper pulley. The plan view may be placed above either one of the elevations, and is made according to the ordinary principles of projections, by studying out from the two elevations already made how the pulleys are located with relation to each other, and drawing them as they would appear if looked at from above.

A careful study of the figure will show that point A is vertically over point B, so that in plan the projections of the two points coincide, or, as it is stated in shop language, the leaving sides of the pulleys are in the same plumb line.

We now have the drawing completed as far as is necessary to determine the location of the pulleys, it being unnecessary to draw the arms, hubs, etc., of the pulleys in a drawing which is made to show location of pulleys on the shafts. It usually makes the drawing clearer, however, if the belt is shown also, and to make the drawing of the belt, the width and thickness must of course be known. The belt should always be put on so that the same side of the belt touches both pulleys when it is possible to do so. We will call the side of the belt which touches the pulleys the inside, and the other side the outside. Now referring

first to the left-hand elevation in Fig. 42, where the belt lies around the circumference of the upper pulley, from the point C, where the upward-moving part of the belt strikes the pulley, around to A, where the downward-moving part leaves the pulley, only the edge of the belt is visible, and is represented by drawing an arc of a circle from line O C around to O A with a radius equal to the radius of the pulley plus the thickness of the belt. The location of C may be found near enough for all practical purposes by drawing a line from B tangent to the upper pulley, C being the point of tangency, and O C is the radius drawn through C. In drawing the arc of the circle from O C to O A it is well to let it run by these lines a little way in the pencil drawing, and that part which is not used may be erased after the drawing is inked. The descending part of the belt leaves the pulley at A, and from that point to the place where it strikes the lower pulley it twists through an angle of 90° , coming out over the front of the lower pulley. The edge of the belt, which we see in its full thickness where it leaves the upper pulley at A, twists toward the left, less and less of it being seen as the belt descends, until at d , where it strikes the other pulley the two corners of this edge coincide, and from there to the bottom of the pulley we see this edge of the belt as a line. At the same time that the thickness of the belt has been disappearing from view, the outside of the belt has been coming into view, until at $d d'$ we see the full width of the belt, the outside corner being the one which is visible. The inside corner is behind the rest of the belt and is shown dotted in the figure, although it is usually omitted entirely. From d' to the bottom of the pulley the two right-hand corners coincide. Points d and d' are found by drawing the horizontal dotted line through D (right-hand view) and laying off on this line a distance equal to one-half the width of the belt each side of line X Y. From $e e'$ the belt goes up under and around the back side of the pulley to $b b'$, where it begins to be drawn off to the left, $b b'$ being on the center line drawn through the shaft, since, by glancing at the right-hand view, we can see that the upward-moving part of the belt leaves the lower pulley at B, which is on a level with the center of the shaft. After leaving $b b'$ the belt remains behind the pulley for a short distance, and is shown

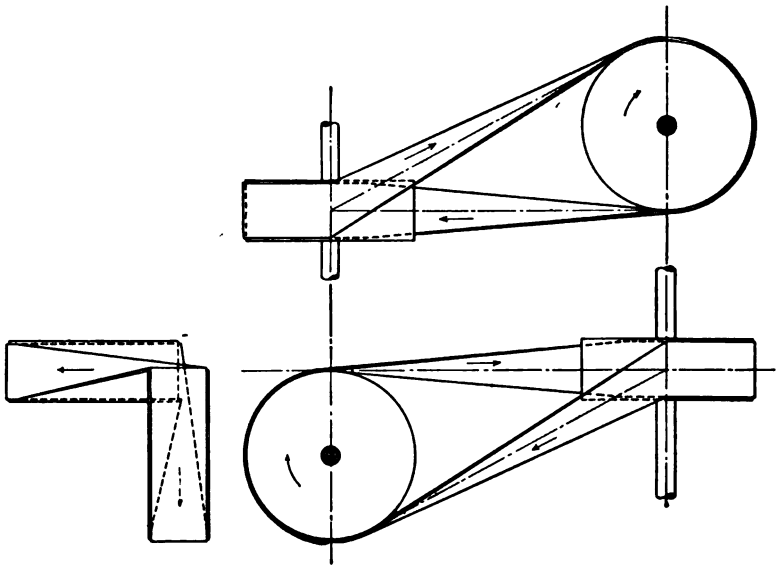


Fig. 44.

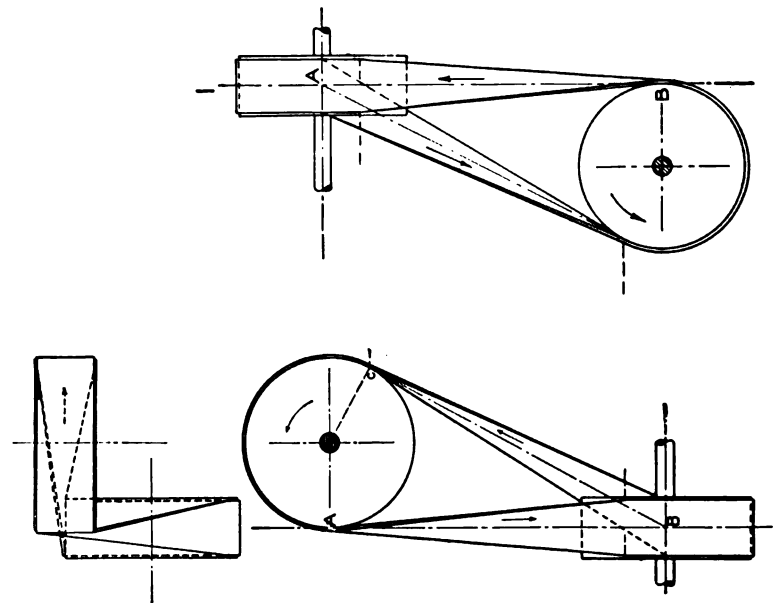


Fig. 48.

dotted. It is projected at its full width at $b\ b'$, but as soon as it leaves the pulley it begins to twist toward the right, the left-hand edge gradually coming into view until it is seen at its full thickness where it strikes the pulley at C. At the same time, the *inside* face of the belt, which is toward the front when the belt leaves the pulley, gradually turns toward the right and appears narrower until it disappears from view, that is, is projected as a line. This completes the left-hand view, and the right-hand view is drawn according to the same principles, as is also the plan view.

An actual belt would not twist uniformly, and its corners would not appear as straight lines, but would curve, the form of the curve depending on the stiffness of the belt, the size of the pulleys, etc., but the straight lines are much easier to draw and represent the belt sufficiently well for all practical purposes.

Figs. 43 and 44 show what changes are made in the location of the pulleys and the appearance of the belt by changing the direction of rotation of the shafts. In Fig. 43 the lower shaft turns in the same direction as in Fig. 42, but the upper shaft turns in the opposite direction. In Fig. 44 the upper shaft turns in the same direction as in Fig. 42, and the lower shaft turns in the opposite direction.

Reversible Quarter Turn with Two Guide Pulleys. The quarter-turn belt of the kind shown in Figs. 42–44 works satisfactorily, provided there is never any reversing of the direction of rotation. Sometimes, however, it happens that the shafting in a shop or mill is caused to make a few turns in the opposite direction from that in which it ordinarily runs. This might be done accidentally, or intentionally in the course of making repairs, and, as has already been stated, if it should occur, a quarter-turn belt such as described above would immediately leave the pulleys. With a small belt this might not be a serious matter, as it could readily be replaced, but with a large belt it would cause delay and might cause damage. Accordingly, if a large quarter-turn belt is to be used, it is desirable to have it arranged so that it can travel in either direction if occasion required. To accomplish this, one or more guide pulleys are used in addition to the pulleys on the main shafts, these guide pulleys being placed on auxiliary shafts so located as to con-

form to the general principle of belting, that the belt may always be delivered into the plane of the pulley which is to receive it. When guide pulleys are used, the main pulleys should be so located with relation to each other that the *receiving* side of the *driving* pulley shall be in line with the *delivering* side of the *driven* pulley, so that the part of the belt which transmits the power from the driving to the driven pulley (called the tight side of the belt) may go direct without passing over the guide pulleys, thus allowing the latter to guide the loose side of the belt back from the delivering side of the driving pulley to the receiving side of the driven pulley.

We will first study the arrangement when two guide pulleys are used. Let the shaft R, Fig. 45, be the driving shaft, and P be the driven shaft, and let the ordinary direction of rotation of each be as indicated by the arrows. Then A is the point on the driving pulley which receives the center of the belt from the delivering point B of the driven pulley, and if R and P are horizontal shafts, A and B should be in the same plumb line, thus giving the tight part of the belt a direct passage from driven to driver, making a quarter turn in its passage. To draw the pulleys so that this condition may exist, start with either shaft (say R) and draw that view which will show the pulley on it as a circle (in this case the left-hand view). Draw the line X Y tangent to the circumference at A, and the point where X Y intersects the center line of the shaft P will be the center of the driven pulley, which will appear as a rectangle in this view. Next draw the other view of the driven pulley, which will appear as a circle, and at the point B on the delivering side draw the line X' Y' tangent to the circumference of the pulley. The intersection of this line and the center line of the shaft R will be the center of the side view of the driving pulley (being the other projection of the point A). It will thus appear that both views of the line A B are perpendicular to a horizontal line, or, in other words, A B is a plumb line. This gives the required locations of the two main pulleys relative to each other.

Next draw the plan view of these two pulleys, these being constructed from the two elevations, according to the ordinary principles of projection.

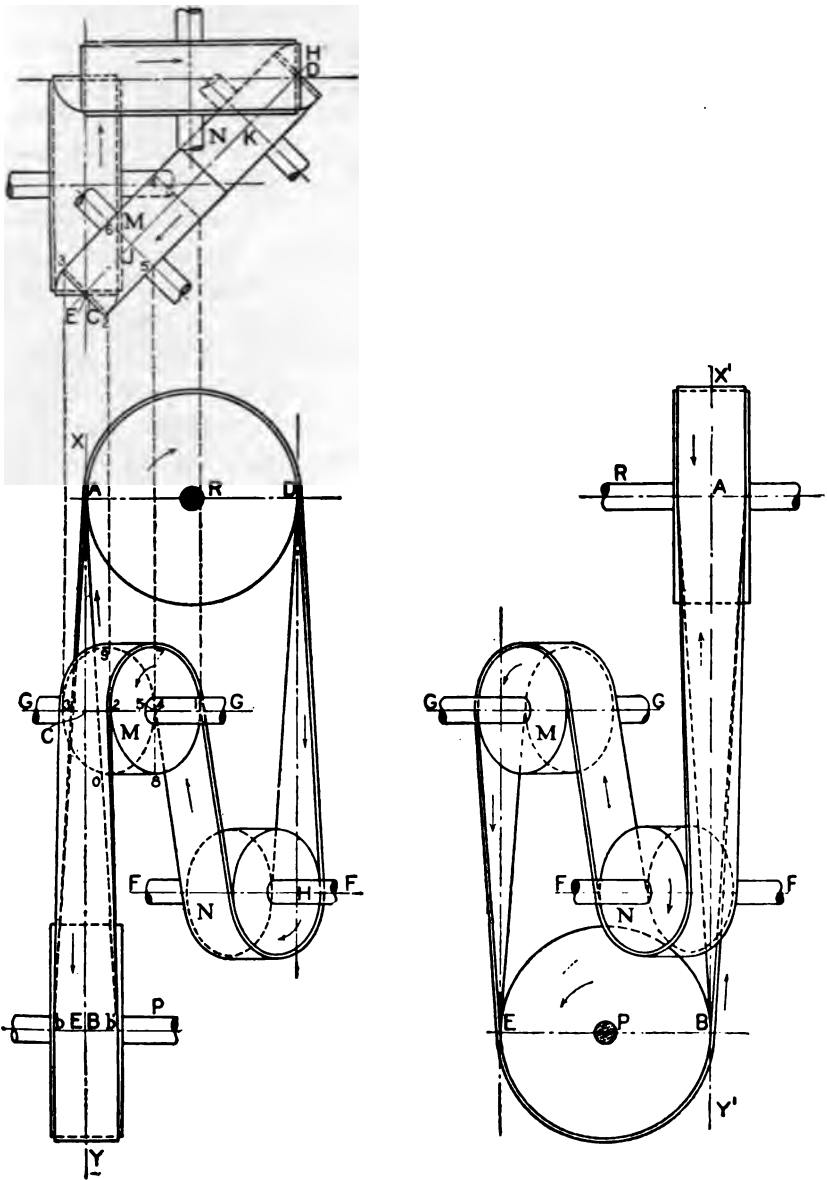


Fig. 45.

When two guide pulleys are to be used, the shafts on which both are located are horizontal if the main shafts are horizontal; the guide pulleys will therefore appear in plan as rectangles. We will accordingly draw the plan view of the guide pulleys first. They are to be so located that their center planes shall coincide, and that the point D, where the belt leaves the driving pulley, shall lie in the center plane of the guide pulley N, and that the point C, where the belt leaves the guide pulley M, shall lie in the center plane of the main driven pulley, in order that the belt will run in the direction indicated by the arrows. In order that the belt may run in the opposite direction if desired, the point E on the main driven pulley must lie in the center plane of the guide pulley M, and the point H of guide pulley N must lie in the center plane of the main driving pulley. In other words, points C and E must be in the same plumb line, and points D and H must be in the same plumb line. Then to draw the pulleys in plan, so that these conditions may exist, draw a line through E and D; this line will be the center plane of the two guide pulleys. From E, measure along the line ED a distance equal to one-half the diameter of the guide pulley M, and from the point J thus found draw a line perpendicular to the line ED; this line is the center line of the shaft on which M is located. In the same way, from D measure off along ED a distance equal to one-half the diameter of the guide pulley N, and draw a line perpendicular to ED through the point K thus found, giving the center line of the shaft on which N is located. Draw the rectangles as shown, representing the plan view of the guide pulleys.

To draw the elevations we must know the distance from the centers of the guide pulley shafts to the main shafts. This may be any convenient distance, it being desirable, however, to remove each guide pulley some distance from the main pulley which delivers to or receives from it, in order that the belt may not be obliged to turn in too short a distance. Draw the center line GG of the shaft for M, and FF of the shaft for N. The guide pulleys will appear in both elevations as ellipses. Consider first the pulley M in the left-hand elevation. Let fall the perpendicular (shown dotted) from point 5 in the plan, to center line GG, giving point 5 in the elevation. Along this perpendicular lay off

the distances 5-7 and 5-8 each equal to one-half the diameter of pulley M. The line 7-8 is the major axis of the ellipse which represents the right-hand edge of M. Now from points 1 and 2 in plan, drop perpendiculars cutting G G at 1 and 2 in elevation. Line 1-2 is the minor axis of the ellipse, and the ellipse 1-7-2-8 may be drawn by any geometric method for constructing an ellipse when its two axes are known. The ellipse 4-9-3-0 is drawn in the same way, and the lines 9-7 and 0-8 drawn tangent to the two ellipses complete this elevation of M. The elevation of N is found in exactly the same way. The same principles are used in getting the other elevation of the guide pulleys.

We have now completed the drawings of all the pulleys, and it only remains to draw the belt as it would appear in the different views. Here, as in the preceding cases, we will represent the edges of the belt by straight lines in the elevations, although they would really be curves. In the plan, where the belt turns as it drops directly from one pulley to another, the edges are represented by arcs of circles. Let us start with the left-hand elevation, with the tight part of the belt (that is, the part which goes directly from B to A). As we are looking at the pulleys in this view, B is on the back side of the pulley, and at B the belt is projected at its true width; as it rises it twists toward the right, so that the edge *b'*, which was at the right when leaving the lower pulley, recedes to the back edge of the upper pulley, while the edge *b*, which was at the left when leaving the lower pulley, comes forward to the front edge of the upper pulley; and we see this edge of the belt in its true thickness where it comes tangent to the upper pulley, and all the way around this pulley until it leaves it again at D. Here it begins to twist to the right again as it goes to the guide pulley N, goes around the lower side of N, then up over and down on the front of M, leaves M opposite the center, and drops direct to the front side of the main pulley, twisting again to the right, completing the quarter twist that was partly made when dropping from D to H. The appearance of the belt in the right-hand elevation is reasoned out in the same way, and a careful study of the figure should make it perfectly clear how to draw the belt. It will also appear that each side of the belt comes successively in contact with the pulleys, so that the belt is put

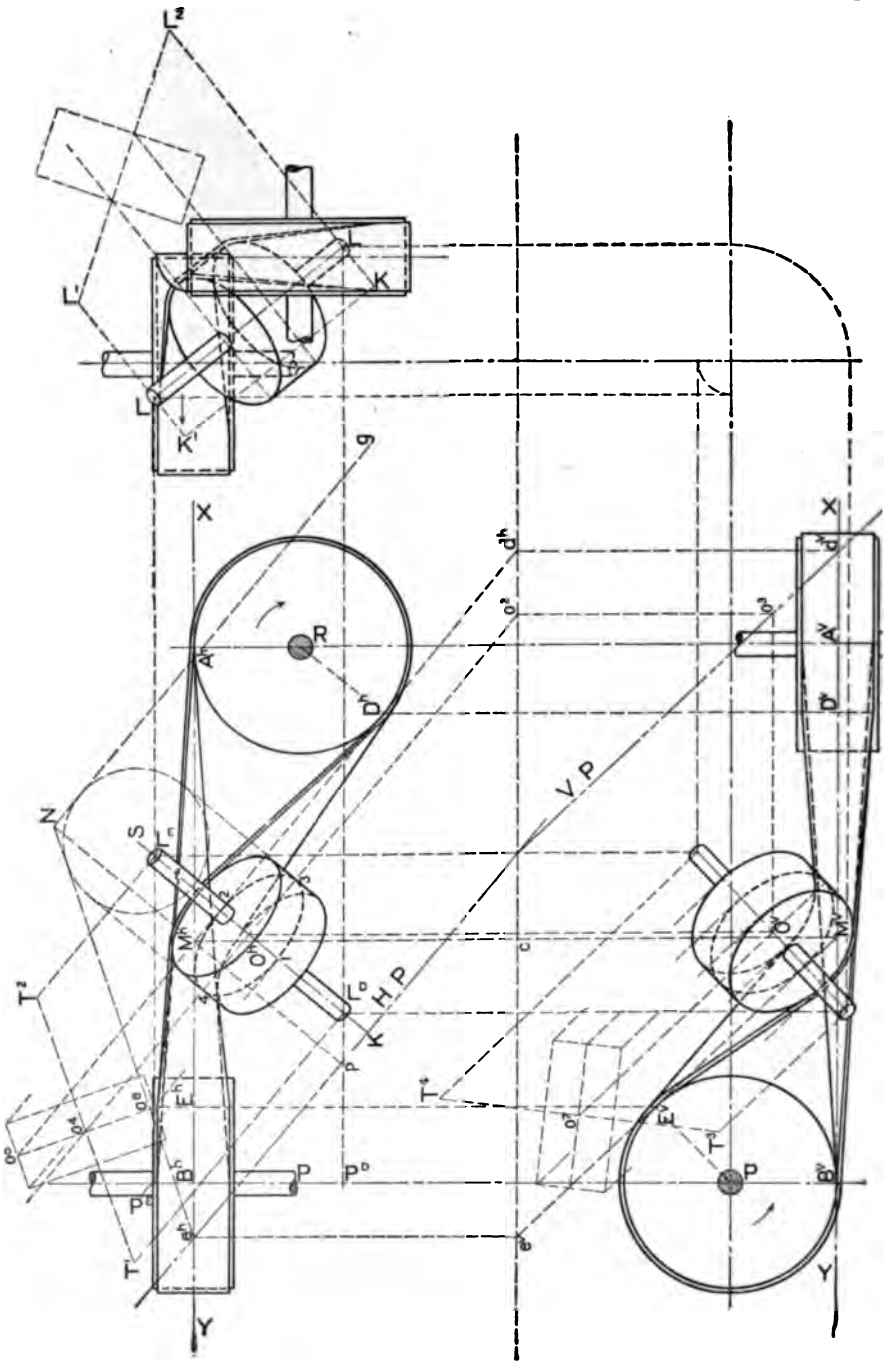


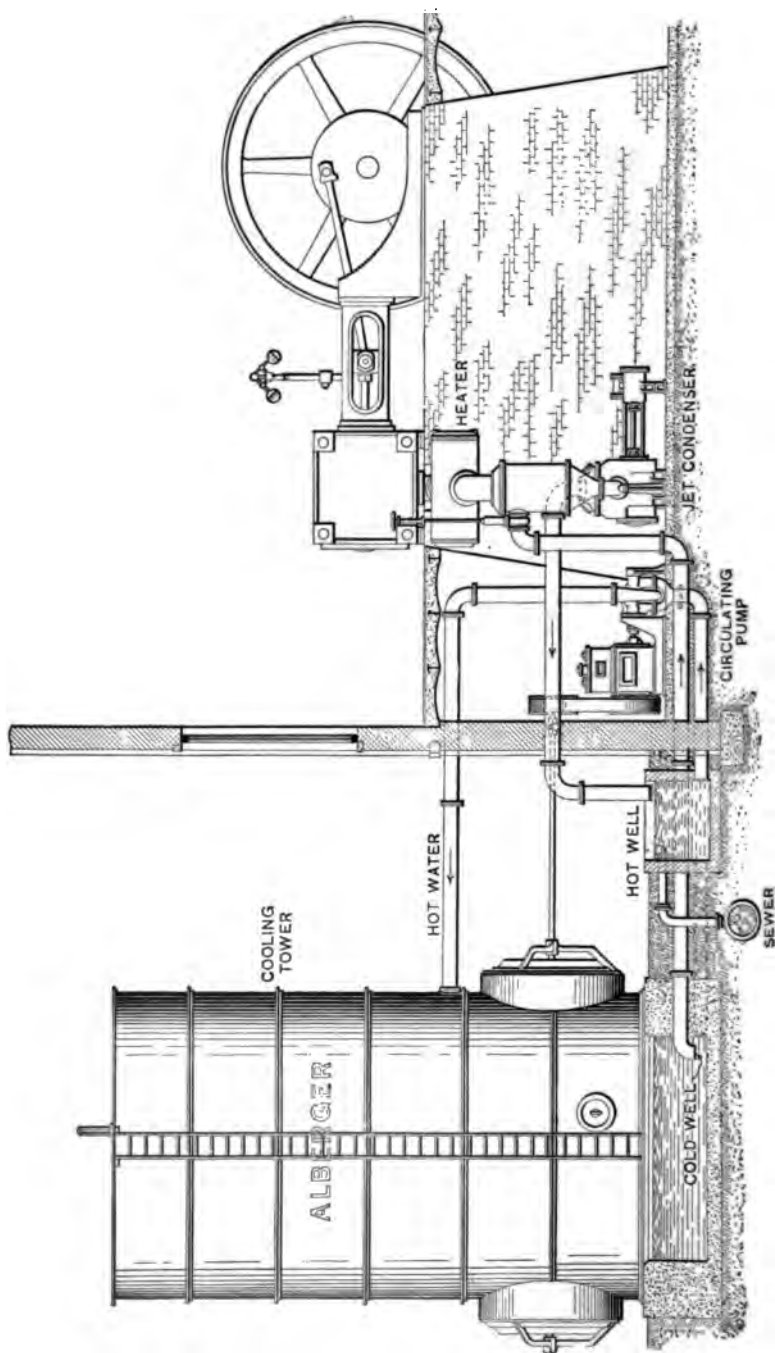
Fig. 46.

together with a twist in it. It is usually desirable to have only one side the working side, but if such were the case with this arrangement of pulleys it would bring a sharp twist in the belt at some part, which might be a greater objection than having the belt work on both sides.

Reversible Quarter Turn with One Guide Pulley.* Fig. 46 shows the arrangement of the pulleys for the belt to run in either direction, using only one guide pulley. The ordinary direction of rotation is that shown by the arrows. The upper pulley is the driver, and, as in the case where two guide pulleys are used, the tight part of the belt goes directly from one main pulley to the other, the slack part of the belt returning over the guide pulley. The shaft of the guide pulley must be set at an angle with both main shafts in order to guide the belt properly. The method of locating the main pulleys is exactly the same as in the case where the two guide pulleys are used, so that the explanation given for that case will apply here, and all we need to consider in this case is the location and drawing of the guide pulley. We will first consider the two elevations. The plumb line $X Y$, as well as being the center line of the tight part of the belt, is the line of intersection of the center planes of the two main pulleys. Choose a point in the line $X Y$, which may be anywhere along the line, depending on how far the guide pulley is to be from one or the other of the main shafts, but preferably about halfway between them. The point is marked M^h in the left-hand elevation, and M^v in the right-hand elevation. From M^h draw a line tangent to the upper pulley at D^h , and from M^v draw tangent to the lower pulley at E^v . The other projection of the line $M^h D^h$ will be $M^v D^v$, coinciding with $X Y$ in the right-hand elevation; and the other projection of $M^v E^v$ will be $M^h E^h$, coinciding with $X Y$ in the left-hand elevation. We now have two lines, $M D$ and $M E$ (shown respectively by their two projections, $M^v D^v - M^h D^h$ and $M^v E^v - M^h E^h$), which determine the plane of the guide pulleys and which are practically the center lines of that part of the belt which passes over the guide pulley, and our problem is one of projections. The problem is to find on the drawing paper the traces of the plane which contains the two lines, and which is the center plane of the

*This subject is optional.

guide pulley. Revolve this plane about one of its traces until it is parallel to the plane of the paper, so that the true angle between the lines will be shown; then draw the guide pulley tangent to the lines in their revolved position, and revolve the lines back to their former position, revolving the guide pulley back at the same time. To carry out this construction proceed as follows: draw a ground line anywhere between the two elevations, parallel to XY , and for the time being consider one of the elevations as a horizontal projection and the other as a vertical projection, remembering that our drawing is made as if projected on two planes located as in Fig. 5, Part IV, or, as it is commonly expressed, "in the third quadrant." We will treat the left-hand elevation as if it were the horizontal projection, and the right-hand elevation as if it were the vertical projection. Extend line $M^h D^h$ until it meets the ground line at d^h , and at d^h draw a perpendicular to the ground line meeting XY (which is the same as $M^v d^v$ extended) at d^v . Through d^v draw a line parallel to $M^v E^v$, and this line, which is marked VP , is the vertical trace of the plane which contains the lines MD and ME . In like manner find the horizontal trace by extending $M^v E^v$ to meet the ground line at e^v , erecting a perpendicular at e^v to meet $M^h E^h$ at e^h , and drawing HP through e^h parallel to $M^h D^h$. If the work is correctly done, HP , VP and the ground line will intersect in a common point. Now through M^h draw a line perpendicular to HP , meeting HP at p . Construct the right triangle $t m^h P$ (Fig. 47), making $m^h P$ equal to $M^h p$ on Fig. 46, and making $m^h t$ equal to the perpendicular distance of M^v from the ground line in Fig. 46 (that is, equal to $c M^v$). Then take the distance $p t$ (Fig. 47) and lay it off on the line $p M^h$ (Fig. 46) from p , thus obtaining point N . Join N and e^h , and through N draw $N g$ parallel to $M^h D^h$. The lines $N e^h$ and $N g$ are the projections on the horizontal plane of lines ME and MD respectively when the plane P , which contains these two lines, is revolved so that it is parallel to the horizontal plane. Therefore the angle $g N e^h$ is the true size of the angle between lines ME and MD . Now with a radius equal to the radius of the guide pulley which is to be used, draw a circle which shall be tangent to the lines $N e^h$ and $N g$. This circle is the center circle of



COOLING TOWER, JET CONDENSER, AND CIRCULATING PUMP.
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pulley revolved parallel to the horizontal plane, and its the revolved position of the center point of the guide of course lies in the plane P. To revolve the center of the guide pulley back so as to get its two projections in the position which it actually occupies with relation to the main pulleys, we will first revolve back the point S to its original position. To do this, draw $S K$ perpendicular to $H P$. Then in Fig. 47 draw $P t$ along the line $P t$ the distance $P V$, equal to $S K$ in Fig. 46. Care must be taken to lay off this distance from P rather than from t , and in order to remember from which point to measure, the student can bear in mind that the distances measured along the hypotenuse in Fig. 47 represent distances measured along $H P$ (Fig. 46). Having thus found V , draw a line perpendicular to $H P$ meeting it in o^h , take distance $o^h P$ in Fig. 46, and lay it off from K along $H P$ (Fig. 46), thus getting O^h . Then O^h will be the center of the ellipse which represents the center circle of the guide pulley in its actual position. Point S cuts $M^h D^h$, will be one end of the major axis, and point 1, found by

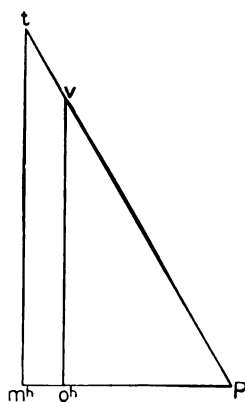


Fig. 47.

$O^h 1$ equal to $O^h 2$, will be the other end of the

The major axis is found by drawing a line through S to $M^h D^h$ and laying off along this line from O^h the distances $O^h 3$ and $O^h 4$ each equal to the radius of the guide pulley. Having now found the two axes of the center ellipse, draw it by any geometric method for constructing ellipses.

We will next find O^v by prolonging the major axis of the ellipse just found until it meets the ground line at o^2 , then draw a line perpendicular to the ground line at o^2 to meet $V P$ at o^3 , drawing a line parallel to the ground line, and from o^3 draw a line perpendicular to the ground line which shall intersect the ground line at O^v . This point will be the vertical projection of the center of the middle circle of the guide pulley ellipse, which is the vertical projection of this middle

circle, is found from O^v in a way exactly similar to that in which the ellipse for the horizontal projection was found from O^h .

The next step is to draw the guide pulley and its shaft, and to do this we will revolve the center ellipse over in each view in such a way that we will have it projected as a line. We will take the horizontal projection first. Extend the major axis of the ellipse from O^h to o^4 , making $O^h o^4$ equal to the perpendicular distance of O^v from the ground line. Draw $O^v 1$ through point 1 parallel to $O^h o^4$. With o^4 as a center and with a radius equal to the radius of the guide pulley, cut $o^6 1$ at o^6 , and cut $D^h M^h$ extended at o^5 . Points o^6 , o^4 and o^5 will be in a straight line, and the line joining them will be the edge view of the center circle of the guide pulley. About this line $o^6 o^5$ draw a rectangle as shown, the width of the rectangle being made equal to the width of the face of the guide pulley. Through o^4 draw a line perpendicular to $o^6 o^5$, which will be the revolved position of the center line of the guide-pulley shaft. The method of revolving back to get the axes of the ellipses, which are the projections of the edges of the pulley in its actual position, and to get the projection of the shaft, will be clear from a careful study of the figure.

The vertical projection of the guide pulley is found by revolving over in exactly the same way, the distance $O^v o^7$ being equal to the perpendicular distance of O^h from the ground line. It is well to assume a definite length for the shaft, whether this be the actual length which the shaft would be made or not. The length assumed in the figure is $T^1 T^2$ (same as $T^3 T^4$), and half of this is laid off each side of o^4 in the revolved horizontal projection.

This completes the two elevations of the guide pulley. The plan is drawn as follows: find the projection $L L$ of the two ends of the shaft as shown by the construction lines, then revolve over by drawing line $K K^1$ at any convenient place parallel to $L L$, drawing perpendiculars through the two points L meeting the parallel line at K and K^1 , and laying off on these perpendiculars the distances $K^1 L^1$ and $K L^2$ equal respectively to $L^p P^p$ and $L^s P^s$ in the elevation. The line $L^1 L^2$, joining the points L^1 and L^2 thus found, is the revolved position of the shaft, and should be equal in length to $T^1 T^2$ and $T^3 T^4$ in the elevations.

We can now draw the rectangle which represents the revolved

position of the guide pulley at the middle of the line $L^1 L^2$, and find the ellipses from this rectangle in the same way as we found the ellipses from the rectangle in the other two views.

The belt is drawn in accordance with the same kind of reasoning as was used in determining the way the belt would look in the other kinds of quarter-turn belts which we have studied.

Belts connecting nonparallel shafts whose axes intersect.

It very often happens that a belt must connect two shafts which are on the same level, but which are not parallel. The connection can be made, whatever the angle between the shafts, by the use of two guide pulleys. If the two main shaft pulleys are of the same diameter, the belt may be made to run in either direction by putting both guide pulleys, or mule pulleys as they are often called, on the same shaft, which will be perpendicular to the plane which contains the axes of the main shafts. That is, if the main shafts are horizontal, the shaft for the guide pulleys will be vertical. If the

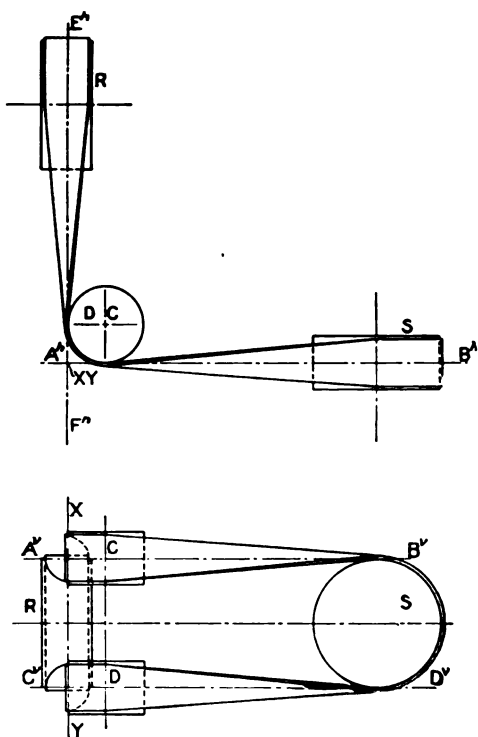


Fig. 48.

main pulleys are of different diameters, the guide pulleys may still be placed on the same vertical shaft, but in this case the belt can run in only one direction. If the belt is to run in either direction, the guide pulleys are placed on separate shafts, which are usually adjustable in position, so that they may be tipped at the proper angle to receive and deliver the belt.

We will first take the case where the two main pulleys are of the same size. Fig. 48 shows the arrangement, the upper view being the plan and the lower view the elevation. R and S are the two main pulleys, and C and D are the two guide pulleys. The line X Y is the line of intersection of the planes of the main pulleys.

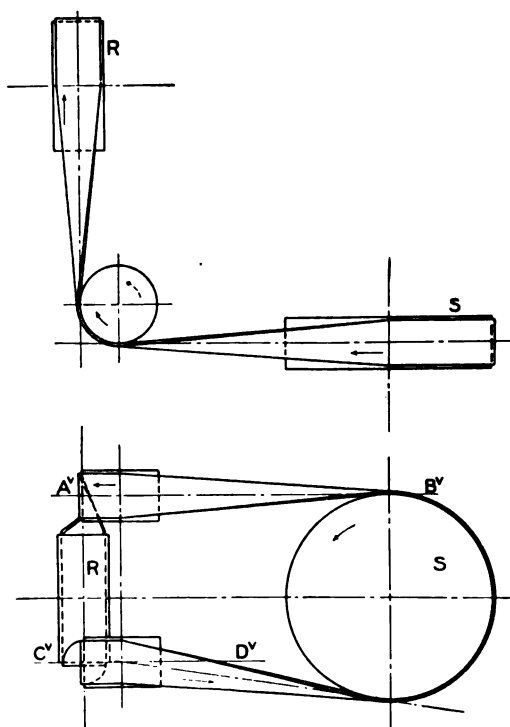


Fig. 49.

The location of the guide pulleys is sufficiently clear from the drawing without further explanation.

Fig. 49 shows the arrangement when the main pulleys are of different diameters. Here the pulleys can turn only in the direction shown by the arrows, for if the direction were reversed the belt would leave the pulleys. The pulleys in plan appear the same as in Fig. 48. In the elevation the upper guide pulley, which receives the

belt from S, has its center plane tangent to the pulley S at the point where the belt leaves S, as shown by the line A' B'. The lower guide pulley, which receives the belt from R, has its center plane tangent to R, as shown by C' D'. If the pulleys were to turn in the opposite direction, the upper guide pulley would have its plane tangent to R and the lower one have its plane tangent to S.

Belt Holes. Very often a belt has to pass through a floor or partition. The holes through which the belt runs should be large enough to be sure that the belt will never strike the sides, but it

is desirable that they should be no larger than is necessary to accomplish that result. Accordingly, the holes should be laid out so that they may be cut in the right place and at the proper angle, the first time. Figs. 50 to 52 show the method of getting the position of the belt holes for the various kinds of belts. The top of the floor only is shown, as it is all that would need to be used in drawing the belt holes, the holes being cut through the floor parallel to the center line of the belt.

In Fig. 50 we have a common open belt. The circles representing the pulleys are drawn, and the belt drawn around them. A short piece of the pitch line is also drawn in each part of the belt where it passes through the floor. These parts of the pitch line are simply lines parallel to, and half-way between, the lines which represent the outer and inner faces of the belt. Next draw the two rectangles which represent the plan view of the pulleys, and draw through them the center line R S. From the points E and H, where the pitch line intersects the line which represents the top of the floor, draw perpendiculars to R S meeting it in points F and G. F and G are the center points of the rectangles 1 2 3 4 and 5 6 7 8, which form the outline of the belt holes on the surface of the floor. The long dimension of the rectangles will be parallel to the shafts on which the pulleys are located. After the belt holes are so found, the distances of their center lines to the right or left of the lines T and X respectively (which are the center lines of the shafts), can be measured on the drawing, and the workman can mark them out on the floor by plumbing down (or up) from the shafts, getting the lines T and X on the floor directly under or over the center of the

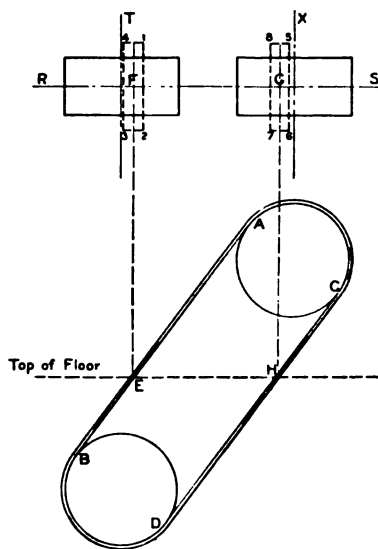


Fig. 50.

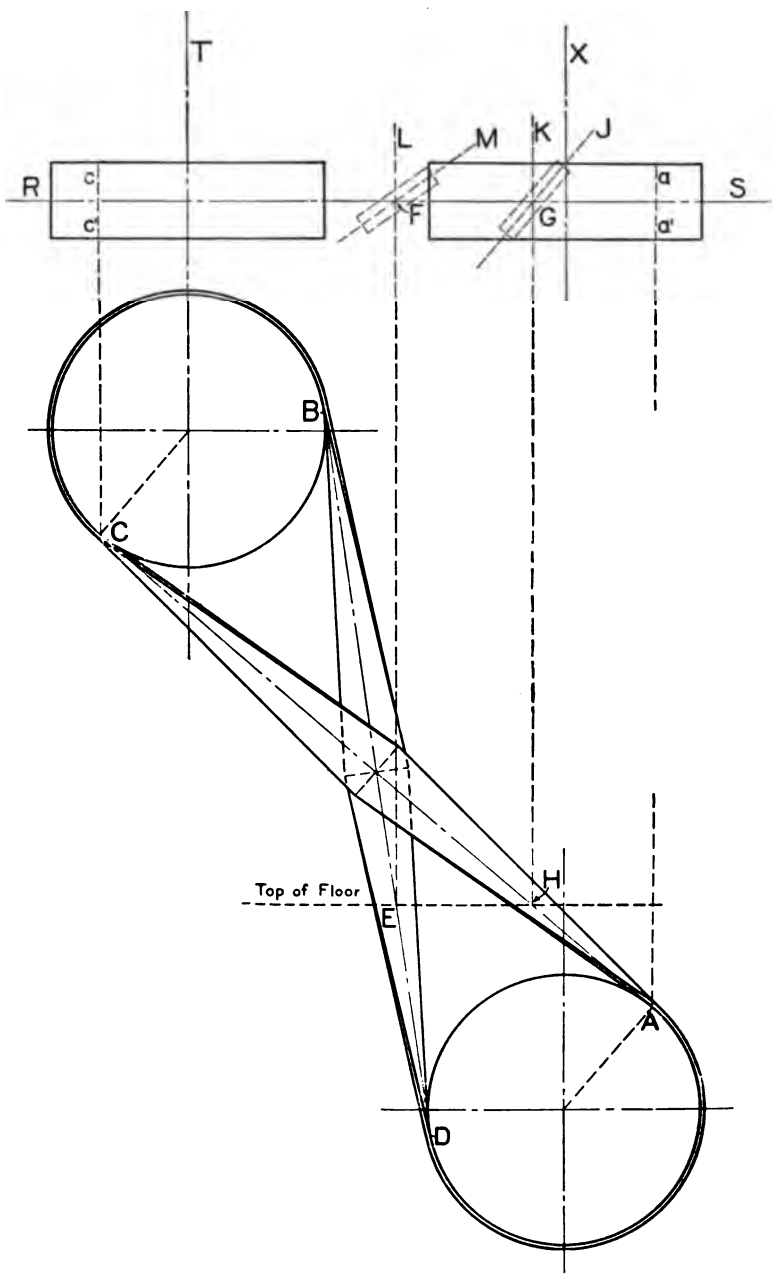


Fig. 51.

shafts, and thus locate on the floor the points F and G, and consequently the belt holes, from the dimensions taken from the drawing.

Fig. 51 shows how to draw the holes for a crossed belt. Draw the two views of the pulleys and the center lines A C and D B of the belt in the elevation; also the center line R S in the plan. It is well also to draw the belt complete in the elevation, as it makes it easier to determine which way the belt holes will slant. From points E and H, where the center lines of the belt intersect the floor line, draw E L and H K perpendicular to R S and meeting R S in F and G. The points F and G are the center points of the belt holes, and it only remains to determine the angles which the center lines of the holes make with T and X respectively. These will be the same as the angles made with H K and E L. When the belt is leaving the pulley at A, a line drawn perpendicularly across to its inner face would occupy the position indicated by the dotted line $a a'$ in plan, and the belt in passing from A to C twists through an angle of 180 degrees, and the line which was at $a a'$ will occupy the position $c c'$. Therefore, when the belt has passed from A to H it will have twisted through an angle which will bear the same relation to 180 degrees that the distance A H bears to the distance A C. That is, if $A H = \frac{1}{4}$ of A C, the angle J G K is $\frac{1}{4}$ of 180 degrees, or 45 degrees. Whether the angle J G K shall be laid off to the right or to the left of line H K, must be reasoned out by considering which way the belt twists in passing from A to C. The angle of the other belt hole (L F M) is determined in the same way.

Fig. 52 shows the method of finding the belt holes of a plain quarter-turn belt, similar to Fig. 50. The centers G and F in plan are found by projecting from the elevation, as shown by the construction lines. The angle which the center line of hole at G makes with the center line of the shaft is found by dividing 90 degrees in the ratio of the distances P and N. The angle of the center line of the belt hole at F with the center line of the shaft is found in a similar manner, by dividing 90 degrees in the ratio of the distance A E to E C. It is usually sufficiently accurate, however, after having found the angle at G, to draw the center line of the other hole parallel to it.

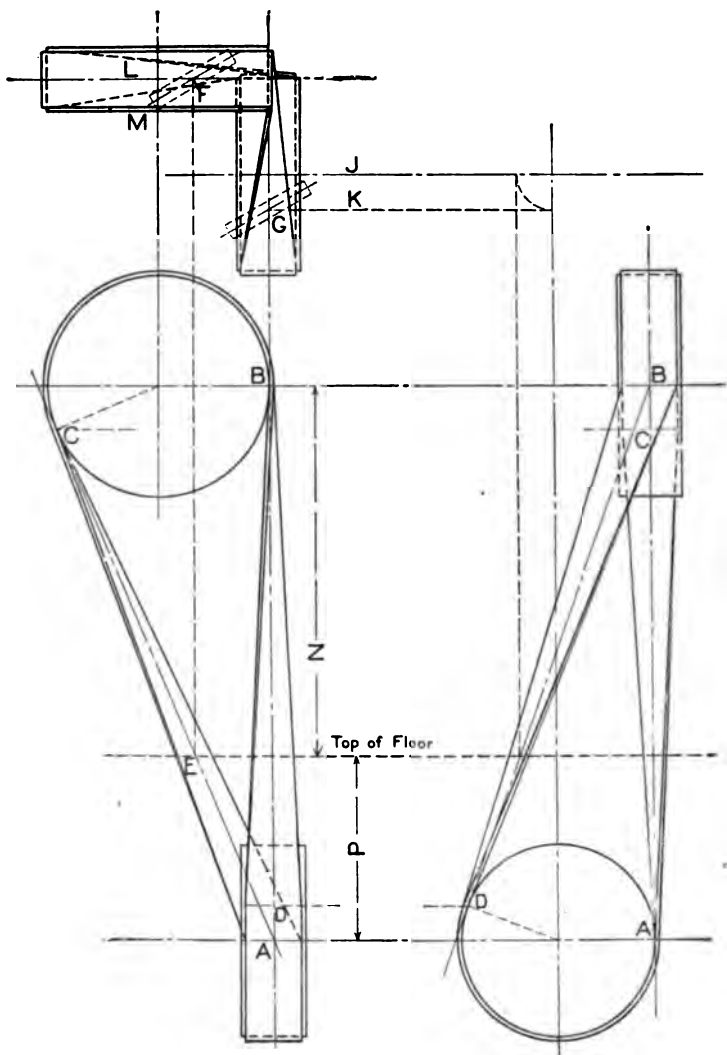


Fig. 52.

TOOTHED GEARING.

If we have a shaft B (Fig. 53), which has fastened to it a circular disc with a smooth circumference of radius B P, and parallel to and at a distance B A from the first shaft, another shaft A, which carries a disc of radius A P, it is evident that the two discs will touch each other at the point P, and if there were sufficient friction between the surfaces of the two discs, rotation of one shaft would cause rotation of the other. The number of turns that A would make would be to the number of turns that B would make as distance B P is to distance A P. In practice, however, the friction between the two discs would not be enough to transmit much power, so some more reliable means must be used.

Wheels having teeth on their circumferences, as shown in Fig. 54, are used in place of these discs. The two dot and dash circles drawn about the centers A and B and in contact at the point P, correspond to the discs of

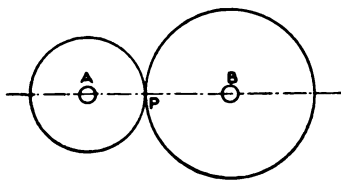


Fig. 53.

Fig. 53, and the gears may be said to be based on these circles, which are called the *pitch circles*. The diameters of these circles are called the *pitch diameters* of the gears. The point P, where the two pitch circles touch each other, is called the *pitch point*. Circles drawn through the outer ends of the teeth are called the *addendum circles*, and circles drawn at the bottom of the teeth are called the *root circles*. That part of the tooth outline between the pitch circle and the addendum circle, as P E, is called the *face* of the tooth, and the part between the pitch circle and the root circle, as P F, is called the *flank* of the tooth. The distance between the addendum circle and the pitch circle, measured on a radial line, is the *addendum*, and the distance between the root circle and the pitch circle, measured on a radial line, is the *root*. The root is made a little greater than the addendum, the difference between the two being the *clearance*.⁶ The distance from the center of one tooth to the center of the next, measured on the pitch circle, as G H, is the *circular or circumferential pitch*, and is equal to the circumference of the pitch circle divided by the number of teeth. In order to run together, two gears must

have the same circular pitch. The numbers of teeth in two gears of the same pitch are proportional to the circumference and, consequently, the diameters of their pitch circles; and as the speeds of the two shafts which are connected by a pair of gears are inversely proportional to the diameters of the pitch circles of the gears, the speeds must also be inversely proportional to the number of teeth in the gears.

On rough gears the width of the tooth (as $L M$) is made a little less than the width of the space ($R L$), to allow for irregularities of construction. The difference in the width of the two is called the *backlash*.

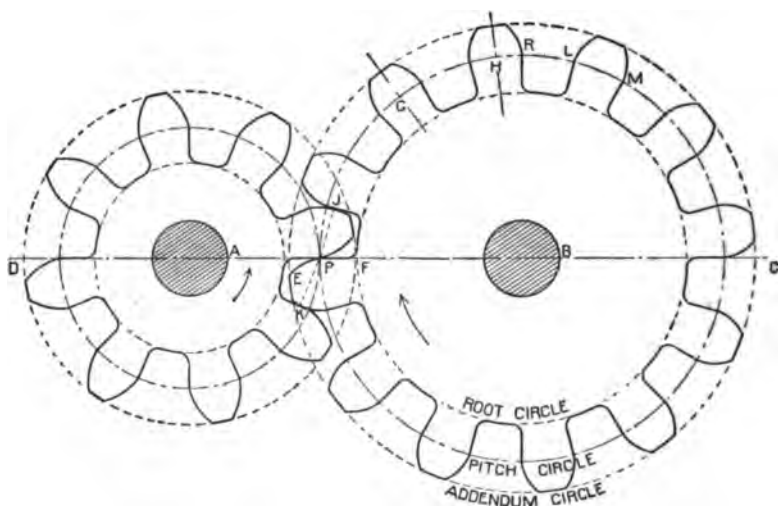


Fig. 54.

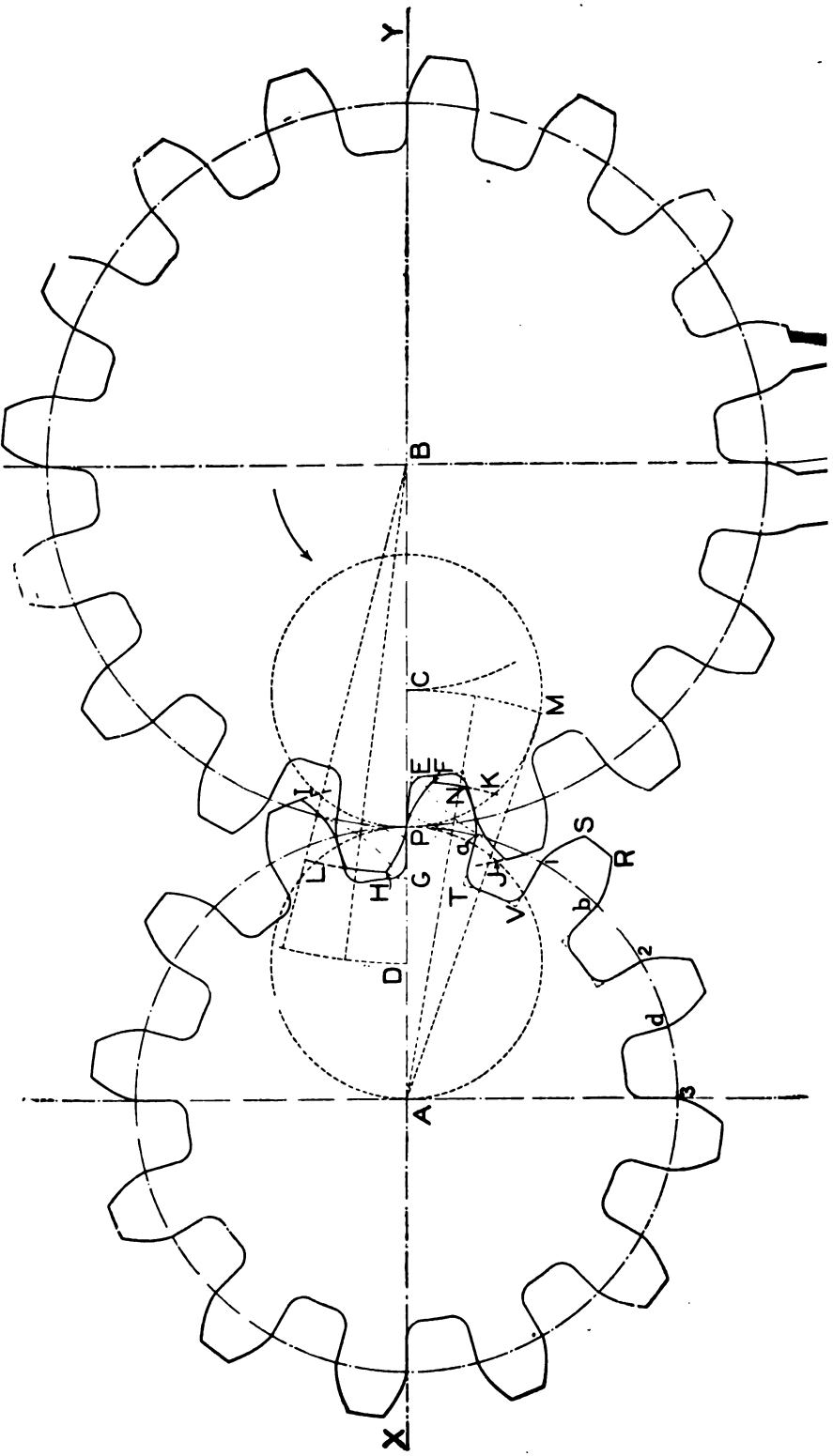
Although the circular pitch is a term which is used frequently in connection with gearing, there is another kind of pitch which is often used. This is the *diametral pitch*, and is equal to the diameter of the pitch circle divided by the number of teeth. The diametral pitch is not a distance which can be measured on the gear, as can the circular pitch, but is merely a term which is used to describe the size of the gear, and which bears the same relation to the circular pitch that the diameter of a circle bears to

its circumference. Since the circumference of a circle is 3.1416 times its diameter, the circular pitch can be found by multiplying the diametral pitch by 3.1416, or the diametral pitch can be found by dividing the circular pitch by 3.1416. In speaking of the pitch of a gear, instead of using the diametral pitch, which is often a fraction, it is customary to use only the denominator of the fraction. For instance, if the diametral pitch of a gear is $\frac{1}{2}$ inch, it would be spoken of as a 2-pitch gear.

If the gear A (Fig. 54) is driving the other gear in the direction indicated, there is a working point of contact between the teeth of the two gears at J and another at K; and as the gears turn and the teeth slide along each other, the point where a pair of teeth are in contact changes. Now, if from the point of contact, as J, a line is drawn to the pitch point P, the tooth curve should be of such form that this line is normal to the curve at the point of contact. That is, P J should be perpendicular to a line drawn tangent to the tooth curve at J. This condition should hold wherever the point of contact of the two teeth is, in order that the gears shall run smoothly and with a uniform velocity. A short way of stating this principle is: The normal to the tooth curves, at the point where they are in contact, must always pass through the pitch point.

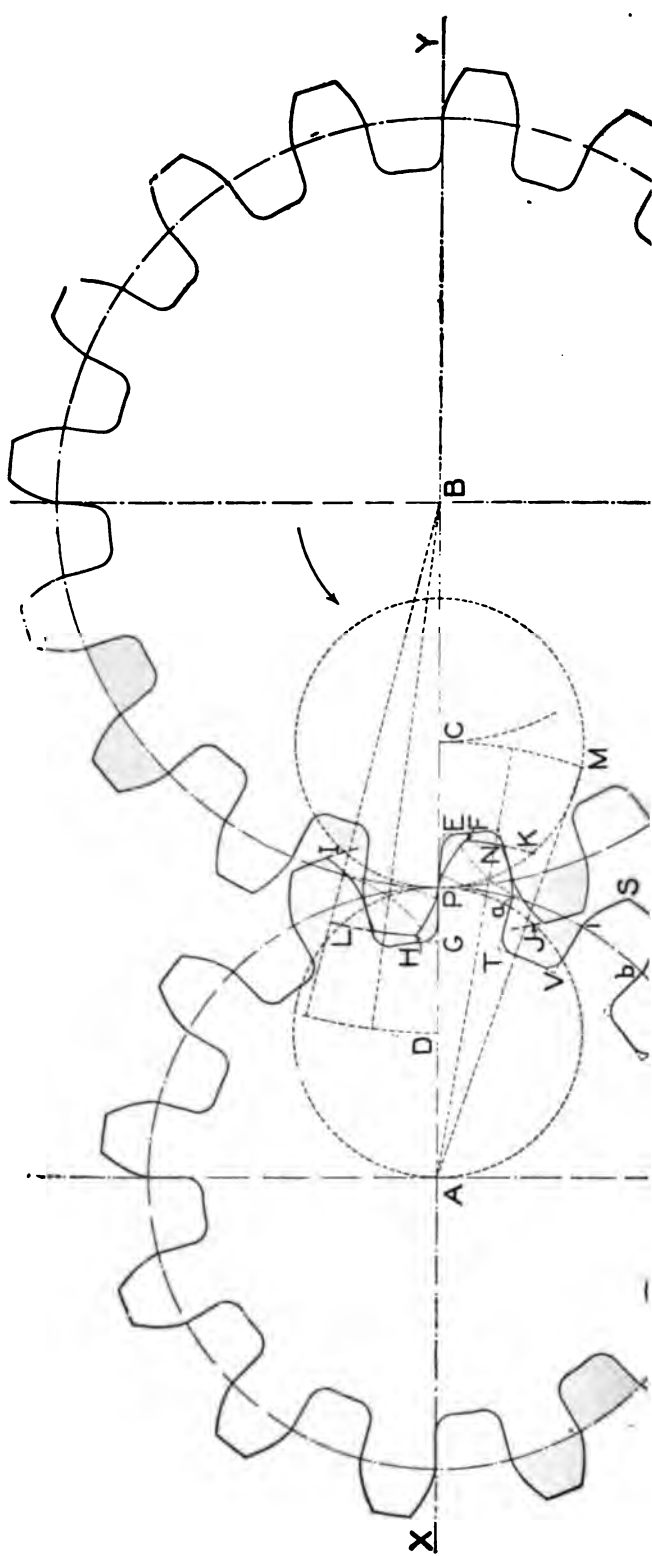
There are two kinds of curves which are commonly used for the outlines of the gear teeth, and which fulfill the above condition. These curves are the cycloidal and the involute curves, the drawing of which was explained in Part II. Although ordinarily a draughtsman is not required to draw the exact outline of gear teeth, yet every draughtsman and every one who has to do with machinery, should understand the principles of gears; and the best way to become familiar with those principles is by studying the method of drawing the various kinds of gears.

Epicycloidal Spur Gears. Fig. 55 shows a pair of epicycloidal gears designed to run together. The centers of the gears are at B and A; the pitch circles are shown in dot and dash, and are in contact at the pitch point P. The circle whose center is C, shown dotted, by rolling on the inside of the pitch circle of the gear B, generates the hypocycloid P E, which forms the flanks of the teeth on gear B; and by rolling on the outside of the pitch



circle of gear A, generates the epicycloid P F, which forms the faces of the teeth on gear A. In like manner the circle whose center is D, by rolling on the inside of the pitch circle of gear A, generates the hypocycloid P G, which forms the flanks of the teeth on A, and by rolling on the outside of the pitch circle of B, generates the epicycloid P H, which forms the faces of the teeth on B. The circles C and D are called the describing circles. If the gear B is the driver and is turning in the direction shown by the arrow, the flanks of its teeth act on the faces of the teeth on A from the point where they first come in contact until the point of contact reaches the pitch point; and from the pitch point on until the contact ceases, the faces of the teeth of B act on the flanks of the teeth of A. In other words, the hypocycloidal part of the tooth curve on one gear is generated by the same describing circle that generates the epicycloidal part of the tooth on the other gear, with which it is in contact. This must always hold true in order to have the gears run properly. The arc I P of the describing circle C, together with the arc J P of the describing circle D, forms what is called the path of contact; that is, the point of contact between the teeth is always somewhere on the line I P J. If the gear A were the driver, the direction of rotation remaining the same, the path of contact would be L P K.

To design a pair of epicycloidal spur gears we must have given the pitch (either diametral or circular), the diameters of the pitch circles, or the number of teeth, and something to determine the size of the describing circles. Manufacturers have found by experience what are the best ratios of describing circles to pitch circles, and gears are designed according to those ratios. It is not well to have the diameter of the describing circle greater than $\frac{5}{8}$ the diameter of the pitch circle, and it is better to have it smaller. If a set of gears is to be made, any one of which is likely to run with any other one, the same size describing circle must be used for the faces and flanks of all the gears; and this describing circle is often taken $\frac{5}{8}$ the diameter of the smallest gear of the set. Sometimes when two gears are not part of an interchangeable set, but are designed to run with each other only, the diameter for the describing circle for the flanks of each gear is



made equal to the radius of that gear, and when this is the case the flanks are radial straight lines, or, as it is usually stated, the gears have radial flanks.

In Fig. 55 the two describing circles are of the same size and equal to the radius of the smaller gear, thus giving radial flanks on this gear. Let us proceed with the design of this pair of gears, given dimensions as follows: gears to be 4 pitch (that is, as explained previously, four teeth per inch of pitch diameter); gear A to have 12 teeth; gear B, 16 teeth; addendum equal to the diametral pitch; clearance equal to $\frac{1}{8}$ of the addendum; describing circles each equal to radius of gear A. The steps in the process of drawing the gears are as follows:

First.—Calculate the diameters of the pitch circles.

Second.—Draw the center line X Y on the paper, and on this center line locate the centers A and B a distance apart equal to $\frac{1}{2}$ the sum of the two pitch diameters. Around these centers draw the pitch circles of diameters as calculated. This will make the pitch circles tangent at the pitch point P.

Third.—Calculate the radius of the addendum circles by calculating the addendum, and adding this amount to the radii of the pitch circles. Then draw the addendum circles with these radii.

Fourth.—Draw the root circles with radii equal to the radii of the pitch circles minus an amount equal to the addendum plus the clearance.

Fifth.—Draw the describing circles tangent to each other and to the pitch circles at the point P.

Sixth.—With the describing circle C rolling on the outside of the pitch circle of A, generate the epicycloid P F, continuing it until it meets the addendum circle of A. With the describing circle D rolling on the inside of the pitch circle of A, on the opposite side of line of centers from which the circle C rolled, generate the hypocycloid P G. Since the diameter of D is equal to the radius of the pitch circle of A, the hypocycloid P G will be a radial line; and consequently, after the student has become familiar with this fact, it will not be necessary to actually roll the circle to generate such a hypocycloid. The epicycloid P F and the hypocycloid P G together form one side of the tooth of gear A.

4th.—Divide the circumference of the pitch circle into equal parts as the gear has teeth, and through these draw curves like the curve G P F. This may be done by a templet of stiff paper that will just fit the curve G P F, means of this templet transferring the curve to the points *a, b, d*, etc., halfway between 1 and 3, etc., since there is to be no backlash, and through these draw curves similar to G P F, but turned so as to curve the other way. Now by filling in with full lines that part of the pitch circle between the points F and N, R and S, etc., and the root circle between T and V, etc., we have the outlines of the teeth on the gear A. In practice, instead of making sharp corners at T and V, as shown by the dotted lines, fillets are used between these arcs of circles, these fillets being made as large as possible and still allow space so that the corner of the teeth on the other gear shall not strike.

5th.—Construct the teeth on the gear B in the same way as those on A were constructed, the describing circle D generating the epicycloid P H by rolling on the outside of the pitch circle of A, and the describing circle C generating the hypocycloid Q I by rolling on the inside of the pitch circle of B. The hypocycloid is not a straight line in this case, as the diameter of C is not equal to the radius of the pitch circle of B.

The following is the method of calculating the diameters of the circles in the above construction. Since the gears are 4 diametral pitch is $\frac{1}{4}$ inch, and the pitch diameter of each gear will be the number of teeth in that gear multiplied by the pitch. Then gear A, having 12 teeth, will have for its pitch diameter $12 \times \frac{1}{4} = 3$ inches; and gear B, having 16 teeth, will have for its pitch diameter $16 \times \frac{1}{4} = 4$ inches.

If the pitch diameters had been given instead of the number of teeth, the latter would have been found by dividing the pitch diameter by the diametral pitch.

ANNULAR GEARS.

An annular gear is a ring with teeth on the inside of it. Fig. 1 shows such a gear, with center at A, meshing with a small gear, often called the pinion. The method of drawing such a

pair of gears is similar to that just described for two spur gears. Here the circle C by rolling on the *inside* of the pitch circle of A generates the *faces* of the teeth of A, and the circle D by rolling on the *outside* of the pitch circle of A generates the *flanks* of the teeth on A. The shape of the teeth of the pinion in the figure is found with the same describing circles placed at C' and D' to avoid mixing up the lines.

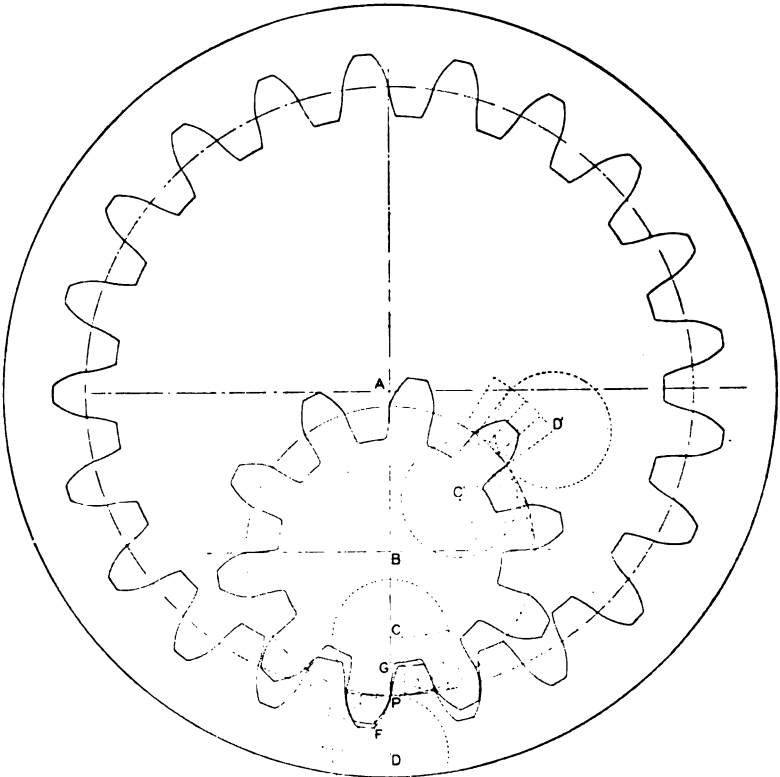


Fig. 56.

In designing an annular gear and pinion the diameter of the annular must never be so small that the distance from center A to center B shall be less than the sum of the radii of the two describing circles. If this should be the case, the teeth will interfere with each other.

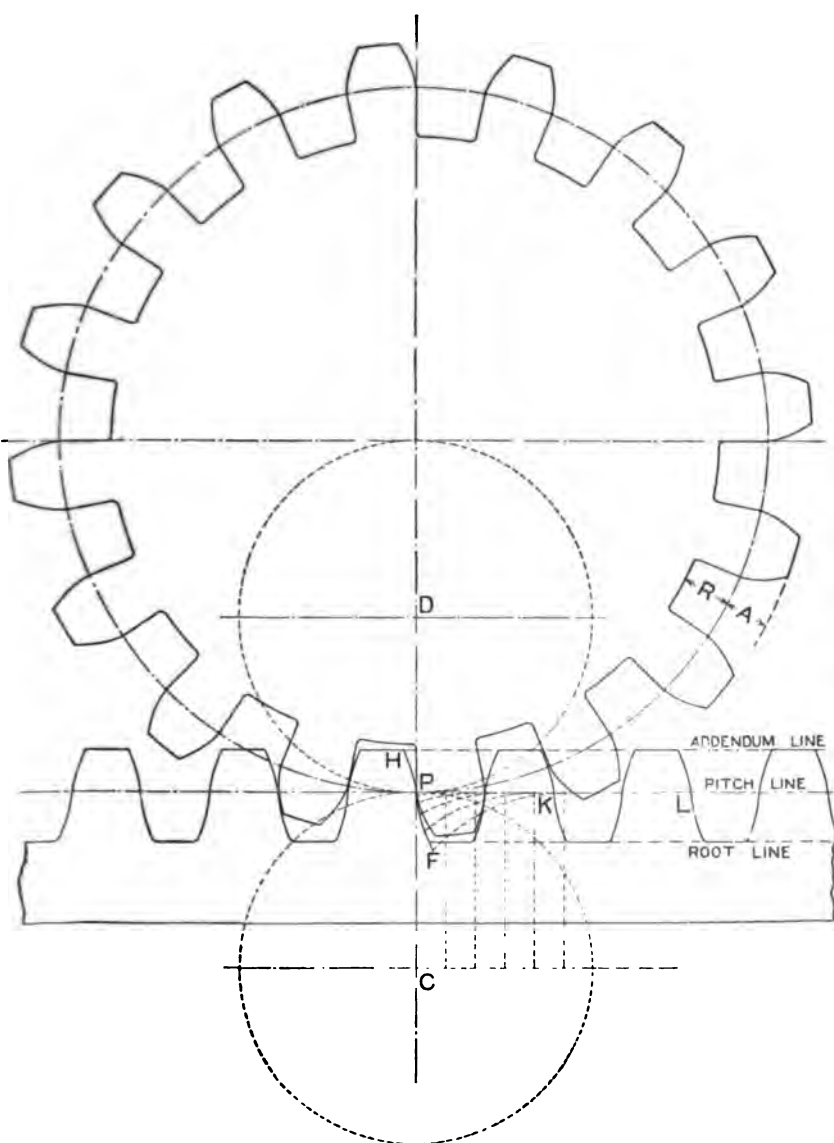


Fig. 57.

RACK AND PINION.

A rack is a gear whose pitch line is a straight line instead of a circle. Fig. 57 shows an epicyclic rack in gear with a 16-tooth pinion. The describing circles are of the same size in the figure, although they might be of different sizes. The teeth on the pinion are drawn as described for Fig. 55, and the construction lines for drawing them are not shown. The curves which form the faces and flanks of the rack are cycloids. The describing circle C rolling on the pitch line of the rack, generates the cycloid P F, which forms the flanks of the rack teeth; and the describing circle D rolling on the pitch line of the rack, generates the cycloid P H, which forms the faces of the rack teeth. The addendum and root lines are drawn parallel to the pitch line, and at a distance from it equal respectively to the distances A and R of the pinion. The teeth are spaced off on the pitch line of the rack by laying off the distances P K, K L, etc., equal to the circular pitch of the pinion.

INVOLUTE GEARS.

Another form of gear teeth which is very common, is the involute. Fig. 58 shows parts of a pair of involute gears and the method of drawing the teeth. The circular pitch and the diameters of the pitch circles are found, and centers A and B located in the same way as described for epicyclic gears. The pitch circles are in contact at the point P, as before. In involute gears the point of contact between the teeth is always somewhere on the line C D, the position of which is determined in designing the gears. This line passes through the pitch point, and the angle which it makes with the line X Y (the tangent to the pitch circles at P) is called the angle of obliquity, and is made what has been found by experience to give good results. It should not ordinarily be greater than 15 degrees. In designing the gears, having drawn the pitch circles, draw the line C D, making the desired angle with X Y, and with A and B as centers, draw circles tangent to this line. These circles are called the base circles. To find the addendum circles lay off on the line X Y the distances P M and P L, which, when possible, should each be as great as the circular pitch. From M and L draw lines perpendicular to C D,

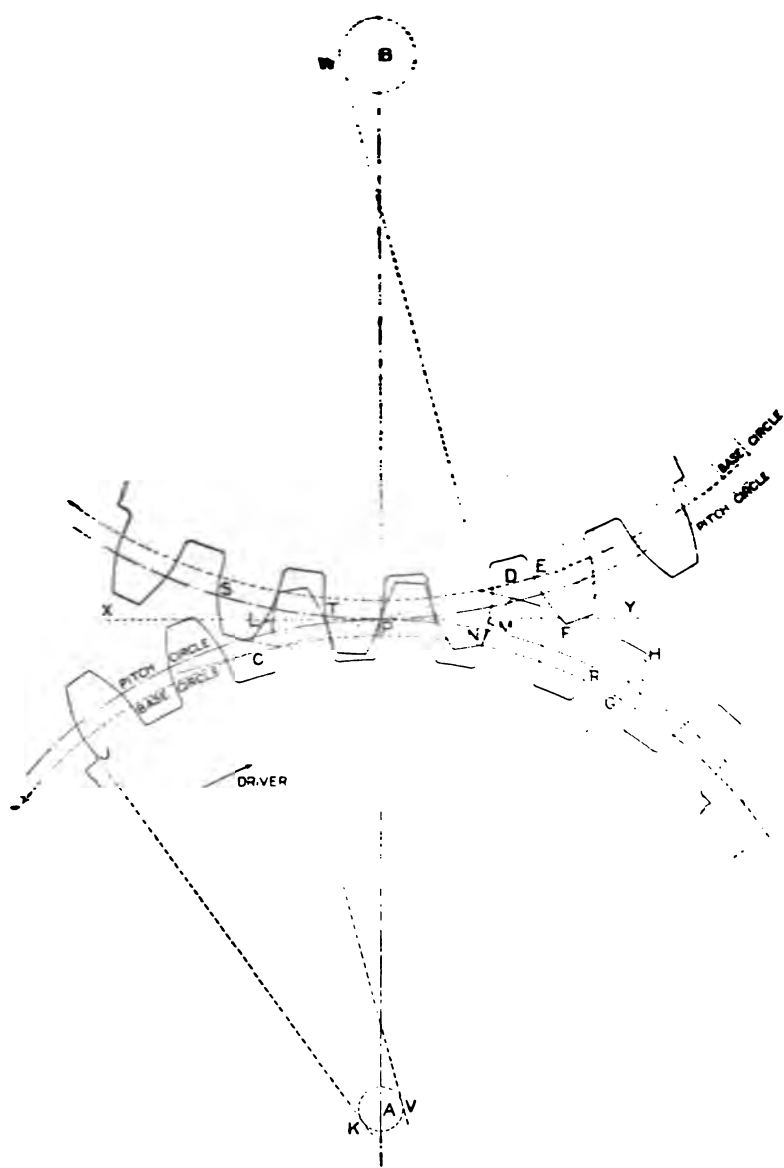


Fig. 58

and draw the addendum circles through the points where these perpendiculars meet C D. The root circles are drawn by allowing a little clearance (about $\frac{1}{8}$ of the addendum). In laying off P M and P L care must be taken that neither one shall be so great that the point where the perpendicular strikes C D shall go outside of where C D is tangent to the base circle. P M plus P L must be at least equal to the circular pitch. At any convenient point on the base circles, as G and E, generate involutes in accordance with the methods described in Part II. Make templates to fit these curves, and by means of these templates draw in the tooth curves through P, N, R, S, T, etc., on the pitch circles, these points being found by spacing off the pitch just as described for epicycloidal gears. This gives us the working part of the teeth, and the remainder to the root circle is drawn by prolonging the perpendiculars, which were drawn through M and L, to V and W, and around the centers A and B respectively draw circles tangent to these lines. The flanks of the teeth are made straight lines tangent to the tooth curves already found and to these circles, as shown at J K. Small fillets are put in at the bottoms of the teeth.

BEVEL GEARS.

When two shafts whose axes intersect, are to be connected by gears, the gears commonly used are what are called bevel gears. The theoretically correct bevel gear is part of the sector of a sphere, but as the designing and making of such a gear is somewhat difficult, a cone is substituted for the sphere.

Fig. 59 shows a pair of *bevel gears* connecting two shafts whose axes intersect at right angles. The cones O P A and O P B are called the pitch cones, and the cones C P B and D P A the normal cones, and it is on these that the outlines of the teeth are laid out. The diameters B P and A P are the pitch diameters of the gears, and are found from the pitch and the number of teeth, just as the pitch diameters of spur gears are found.

To draw such a pair of gears we should have given the angle between the two shafts, the pitch and number of teeth in each gear (from which we find the pitch diameters), and the breadth of teeth P E. The gears might be either involute or epicycloidal. The addendum and root would be determined by empirical rules

1

One tooth on each gear is drawn as described for Fig. 58. With L as a center, draw a series of arcs (shown dotted), cutting the tooth which was drawn on the pitch circle which had L as a center, these same arcs cutting the line $L K$ at points 2, 3, 4, etc.; from 2, 3, 4, etc., draw lines perpendicular to $C D$, cutting $C D$ at 5, 6, 7, etc. From these points draw lines to O . Along $P O$ lay off $P E$ (which must be given), and through E draw a line perpendicular to $P O$, cutting 5 O , 6 O , etc. From the points of intersection draw other lines parallel to $P B$. With center O' taken at any convenient place on $C O$ prolonged, and with radii equal in turn to $a 5$, $b 6$, etc., draw circles as shown. On the circle which is drawn with $H P$ as a radius (marked pitch circle), space off the circular pitch, and on each of the circles in turn lay off the teeth of the same width as they are on the corresponding circles drawn through 1, 2, 3, 4, etc. The rest of the construction can be understood from a careful study of the figure. The other gear is drawn in the same way. Half of each gear is drawn in section in the figure to show the details of the casting.

PLATES.

Plates XX to XXIV inclusive, are to be drawn by the student to give him practice in applying the principles which he has learned of screws, springs, cams, belts and gears. These plates are to be made the same size as those of the preceding Instruction Papers of the course; that is, 11 inches by 15 inches, outside, with a margin of $\frac{1}{2}$ inch, making the part of the plate in which the drawing is done 10 inches by 14 inches.

PLATE XX.

The arrangement of this plate is shown by the reproduced plate.

Fig. 1 is to be a drawing of a right-hand single V-threaded screw 4 inches diameter, 6 inches long, pitch of screw 1 inch. The true helix is to be constructed as shown in Fig. 2 of the Instruction Paper. Show dotted construction lines for one turn of the helix.

Fig. 2 is to be the conventional representation of a single right-hand square-threaded screw 2 inches diameter, $3\frac{1}{2}$ inches long, pitch $\frac{1}{2}$ inch (2 threads per inch).

SCREWS
AND
SPRINGS
EXACT AND CONVENTIONAL
REPRESENTATIONS

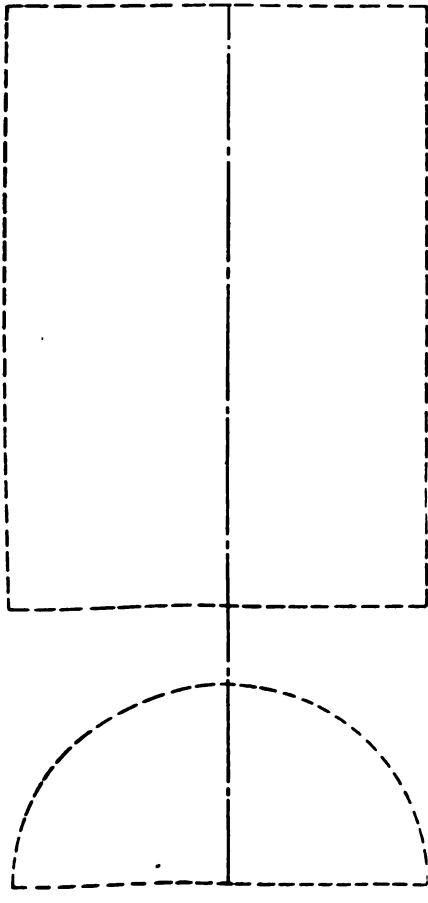


FIG. 1

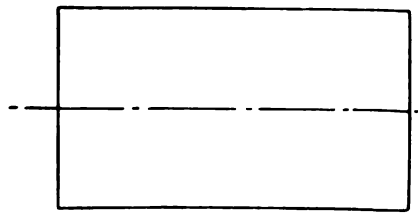


FIG. 2

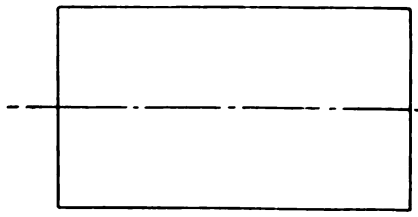


FIG. 3

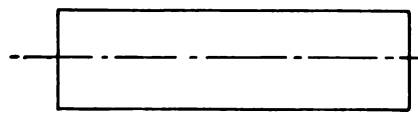


FIG. 4

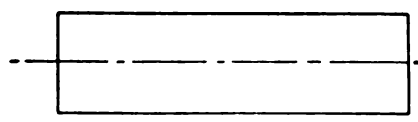


FIG. 5

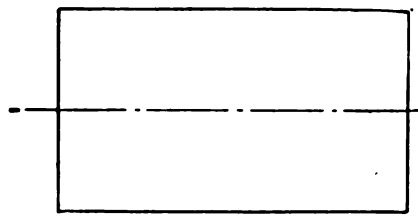


FIG. 6

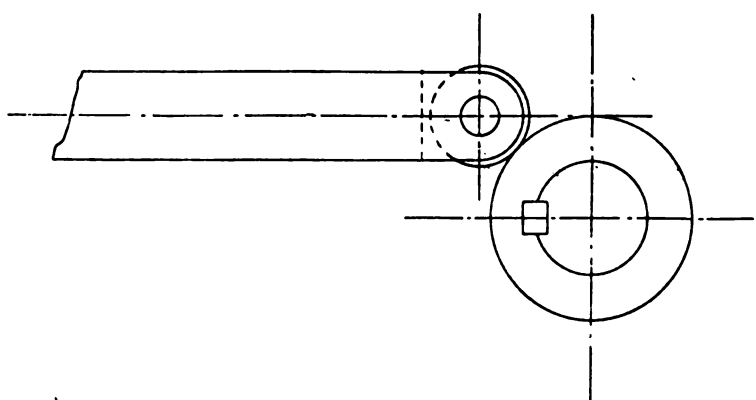


FIG. 2

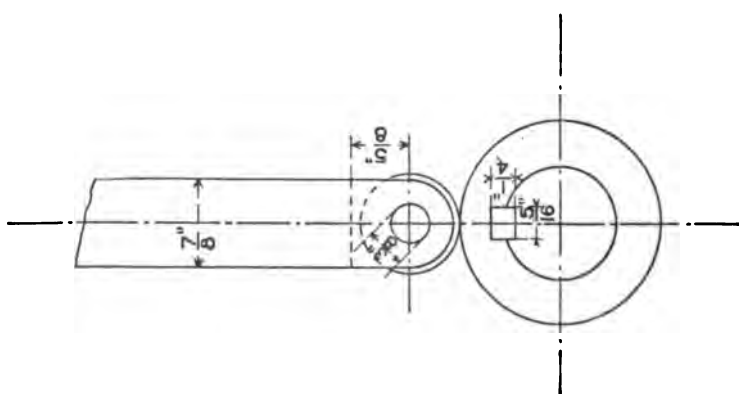


FIG. 1

Fig. 3 is to be the conventional representation of a single left-hand V-threaded screw 2 inches diameter, $3\frac{1}{2}$ inches long, $4\frac{1}{2}$ threads per inch. Use the conventional form shown in Fig. 23.

Fig. 4 is to be a single right-hand V-threaded screw 1 inch diameter, $3\frac{1}{2}$ inches long, 8 threads per inch. Use conventional form shown in Fig. 23.

Fig. 5 same as Fig. 4, except that the thread is to be a double thread, 4 threads per inch ($\frac{1}{4}$ inch pitch).

Fig. 6 is to be a right-handed helical spring of $\frac{5}{16}$ inch round steel, inside diameter of helix $1\frac{3}{8}$ inches, length $3\frac{1}{2}$ inches, pitch $\frac{5}{8}$ inch, as shown conventionally in Fig. 8.

PLATE XXI.

Fig. 1 is to be a plate cam, which, by turning right handed, is to raise a slide (having a roller at its lower end) $1\frac{1}{2}$ inches with harmonic motion while the cam is making one-half of a revolution, then allow it to drop downward to its original position, and remain at rest during the remaining one-half revolution. The center line of motion of the slide is to pass through the axis of the cam. The roller is to be 1 inch diameter, and at its lowest position its center is to be $1\frac{1}{2}$ inches above the center of the cam. The shaft of the cam is to be $1\frac{1}{8}$ inches in diameter and the hub 2 inches diameter. Show one view only. The details of the slide and roller of the hub of the cam are shown in the reproduced plate.

Fig. 2 is to be a plate cam, which, by turning left handed, is to raise a slide and roller, similar to that in Fig. 1, $1\frac{1}{2}$ inches with uniform motion during two-thirds of a revolution of the cam, and return it to its original position with gravity motion in the remaining one-third revolution. The center line of motion is 1 inch to the right of the axis of the cam, and at its lowest position the center of the roller is $1\frac{1}{2}$ inches away from the center of the cam. The dimensions for hub and for roller and slide are the same as for Fig 1.

PLATE XXII.

The reproduced plate shows plan and one elevation of two pulleys located on two shafts which are at right angles to each other. The student is to draw these two views and another elevation, showing the belt on the pulleys in all three views, and put

on arrows to show which way the pulleys will have to turn in order that the belt may stay on the pulleys. The dimensions are given in feet and inches, but of course the drawing cannot be made full size, but must be scaled down. The scale, as stated in the table, is to be 1 inch for every foot; that is, if the distance between the shafts is 8 feet, we draw it 8 inches, and everything else in the same proportion. In other words, everything is drawn one-twelfth of its actual size.

PLATE XXIII.

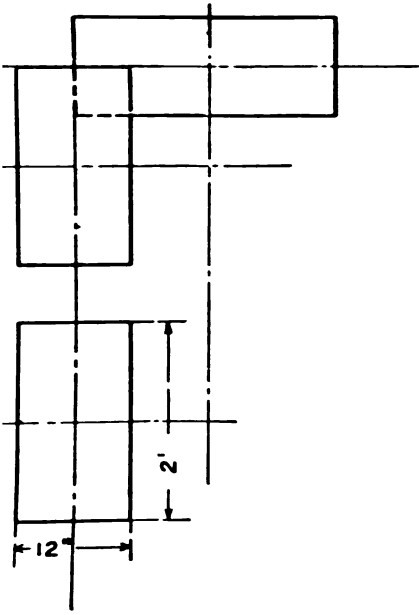
Draw an 8-tooth epicycloidal spur gear meshing with a 20-tooth annular. The gears are to be 1 pitch, addendum of each gear equal to 1 inch, clearance $\frac{1}{8}$ inch. Diameter of both describing circles 4 inches. Draw all of the teeth on the 8-tooth gear, and as much of the annular as there is room for on the plate.

PLATE XXIV.

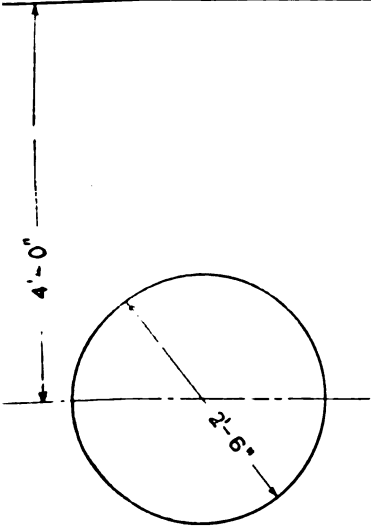
Draw a 24-tooth involute gear meshing with a 32-tooth involute gear. Gears to be 2 pitch, angle of obliquity 15 degrees, addendum $\frac{1}{2}$ inch, clearance $\frac{1}{16}$ inch. Show as much of each gear as there is room for on the plate.

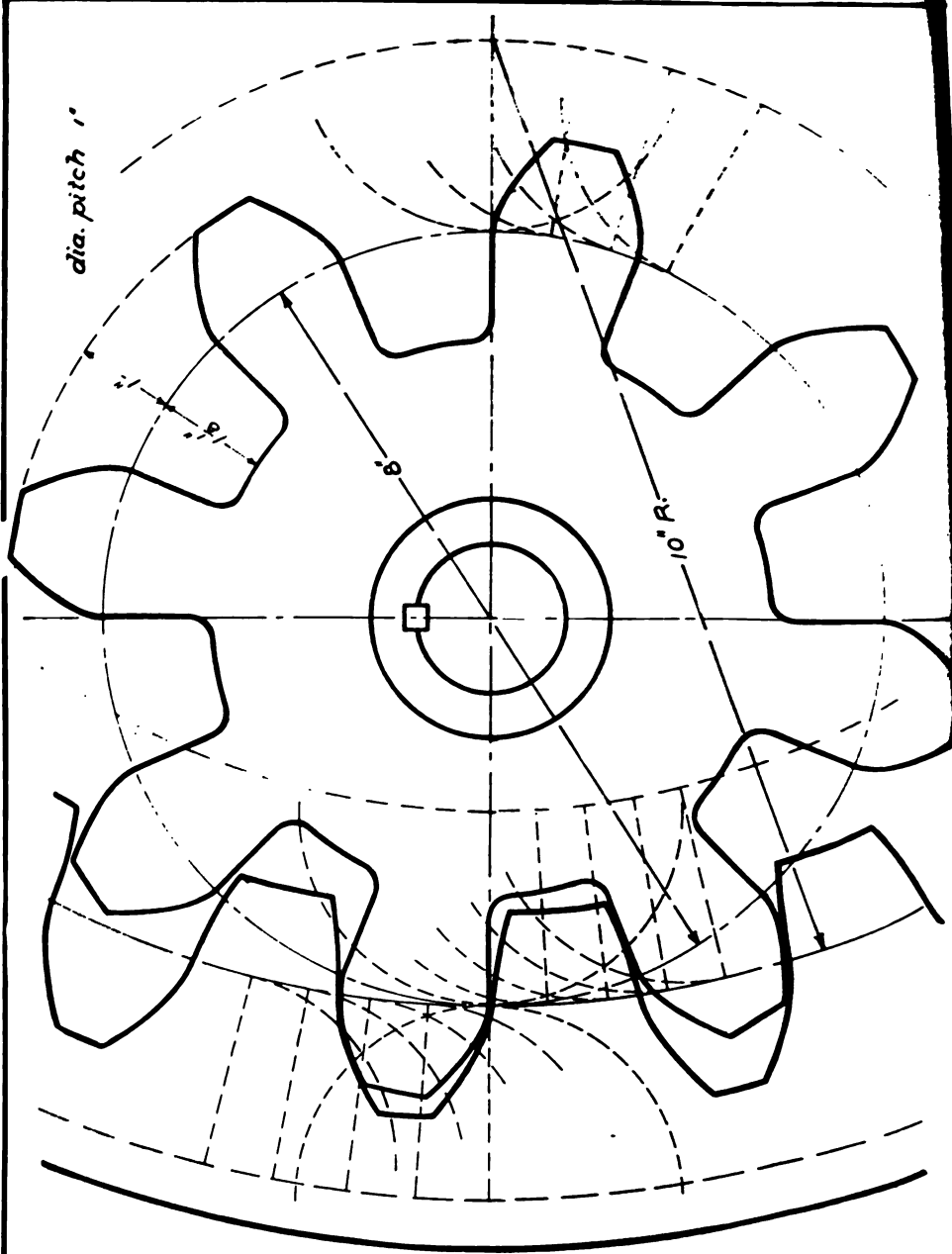
QUARTER-TURN
BELT

SCALE 1" = 1'

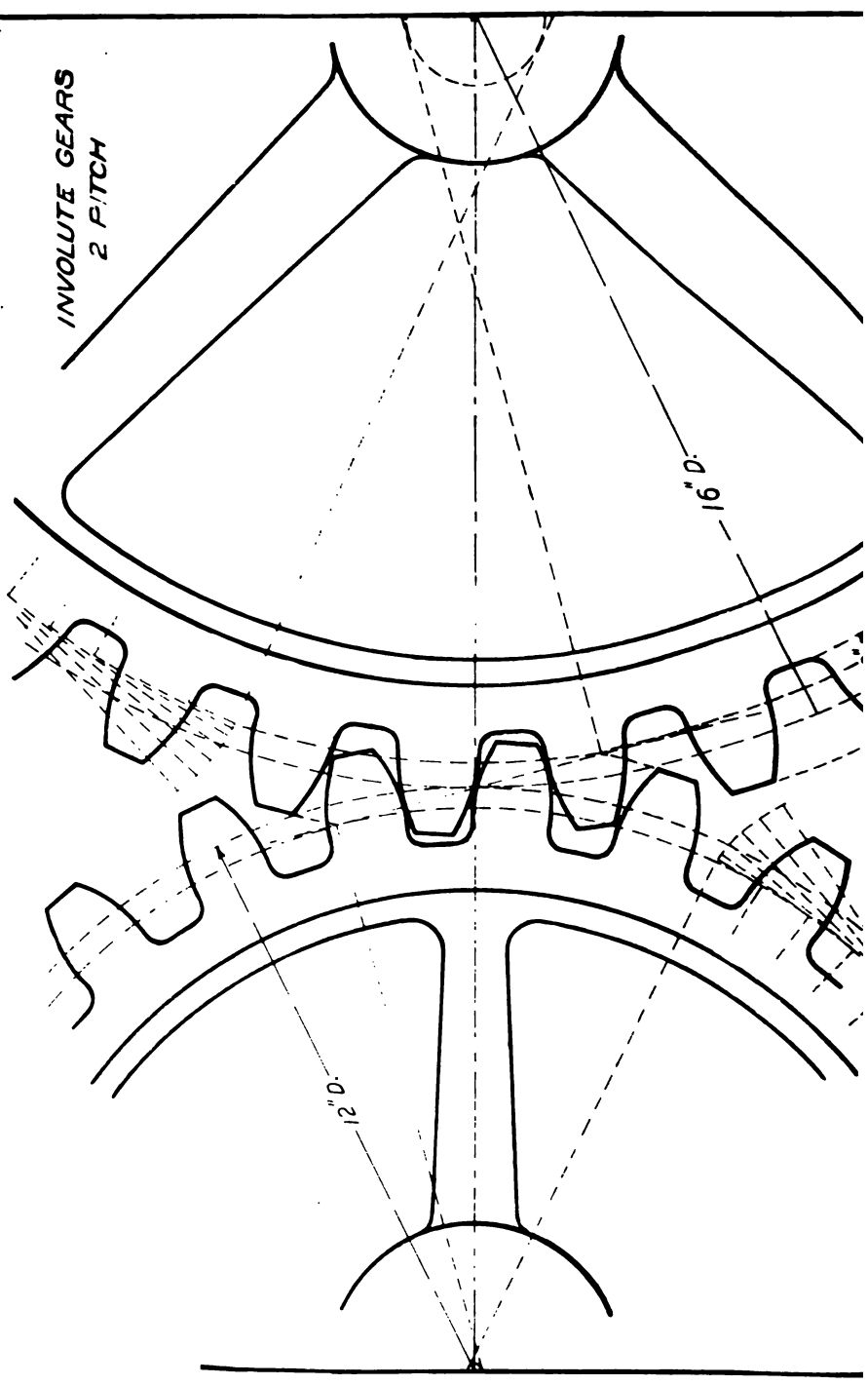


Top of Floor





INVOLUTE GEARS
2 PITCH



MECHANICAL DRAWING.

PART VI.

WORKING SHOP DRAWINGS.

In Parts I to IV, inclusive, the fundamental principles of Mechanical Drawing were explained and illustrated. The production of working drawings has also been discussed to some extent, and the usual characters and symbols explained and applied. The elementary work already outlined has been treated chiefly from the standpoint of correctness of line representation considered by itself, without a detailed study of the use to which the drawings so produced are to be applied.

Evidently this is the proper method, for the student should gain a thorough understanding of the principles which underlie line representation before attempting to apply them to any extended practical use. In all of this preceding work it is intended that the theoretical principles shall overshadow any incidental references made to practical application, however true and pertinent the latter may be for purposes of illustration. Hence, before taking up any advanced work, the student should fully realize the importance, in fact, the absolute necessity, of thoroughly understanding the fundamental principles which have been outlined in the books which have preceded Part VI.

At this point the student must realize that a lack of proper elementary and fundamental training will make him "go lame" at every point of his course, and probably prevent the attainment of proficiency which otherwise would naturally and almost instinctively come with advanced study. It is the thorough and ready knowledge, always at his fingers' ends, of *all* the principles of Mechanical Drawing, which makes the expert draftsman.

Plan and Scope of Advanced Work. It is now intended to throw an entirely different light on the matter, and view the subject of Mechanical Drawing from a purely practical standpoint; viz., that of Utility. It is assumed that the student

understands and can use the principles which have been previously discussed.

If in a working shop drawing we choose to modify any of these theoretical principles, it will be because of increased value in *Utility* of the drawing. For example, we may desire to omit some portions of an elevation or plan or side view of a complicated casting, because certain details will thus be more clearly brought out. We may make a "zigzag" section to show construction which, by absolute fidelity to theoretical principle, would be confused, or hidden in a maze of dotted lines. We may find it convenient to place in some unoccupied corner of a drawing a layout which could not be in the least justified by any rule of projection. A multitude of transgressions like these occur on good drawings, and they are certainly justifiable from the standpoint of *Utility*, which is the true ultimate end sought for in a practical shop drawing.

These variations from the theoretical are not strictly conventionalities, because they are not classified or established, so far as we know, but are the spontaneous outgrowth, as the occasion demands, of the draftsman's purpose to make his drawing one of greatest *Utility*. He can, however, safely transgress a principle only when he thoroughly knows the principle; otherwise a blind deviation from the theoretical path will inevitably lead to difficulty.

All of the above is intended to impress the student with the idea that theoretical principles are his best, in fact, his only tools to work with; but they are not "self-hardening," like "mushet" steel; they are like the finest grade of tool steel, which must be tempered and ground and used with the best judgment of the operator, to secure the most satisfactory results.

Student Drawings. A student's early drawings are usually unsatisfactory, even to himself. Somehow they do not look like those seen in shops, and as a rule he is unable to see why this is so. Of course the difference is to some extent due to the experience of the professional draftsman. However, the superior results of the latter's work are attained largely through his systematic and workmanlike habits of execution. It should encourage the student in his early attempts to know that these essentials to

the infusion of life and shop spirit into a drawing can be analyzed, outlined and grasped at the outset by earnest, intelligent effort, and really good workmanlike results obtained. To discuss, and if possible to impart these essentials of a working shop drawing to the student, is the purpose of the present book.

Essentials. The two chief essentials of a shop drawing, under which general heads a multitude of detail requirements can be summed up, are:

(1.) Absolutely complete and definite instructions from designer to workman.

(2.) Least possible cost in dollars and cents of production of the drawing measured by the draftsman's time.

It makes no difference how much we may attempt to disguise these two elements, the fact will still be apparent that "*complete instructions furnished for the least money*" is what the manufacturing shop is after, and what will be assumed as a basis for judgment as to highest commercial utility.

Completeness of Drawings. As to the first point, that of completeness and definiteness of instruction, there must be no question of degree. If the information which the drawing furnishes is positive and complete, the drawing is good. If doubt arises in the workman's mind as to what the designer intended by a certain line or dimension, or if the dimension be omitted, the drawing is bad. There is no middle ground. The instructions are either present or absent, and the drawing good or bad accordingly.

The workman of to-day is not permitted to assume dimensions or shape. It is his business to execute the draftsman's orders; it is, however, often his privilege to choose his own way of doing it, but further than this modern practice does not allow him to go. He is held as rigidly to the orders specified by the drawing as the locomotive engineer is held to his bit of tissue telegraphic order to proceed, without which he dare not enter the next block. The drawing is supreme; it is official; it must be plain, direct and all-sufficient. It is the draftsman's business to make it thus, and he is not a draftsman until he does.

This idea of positiveness must be thoroughly absorbed by the student. Positive action must be a habit which controls his every

move, which marks every dimension he prints, which directs every line he draws. Every line must mean something, must have a definite reason for existence, must be necessary to illustrate the idea which he wishes to convey to the workman, and every line must be a definite measurable distance from every other line, so that its location is fixed beyond a doubt. Lines which mean nothing, and cannot be measured, have no place on the drawing; they only confuse it.

A good picture of a machine could scarcely be called to the same service as a good drawing of it. The picture might give us an excellent idea of the machine, but for the purpose of the actual construction the picture is useless, while the drawing is of positive value. This value exists simply because of, and in proportion to, the completeness of detail which it shows. Hence in making a shop drawing the picture idea is entirely subordinate to the idea of *Utility*, the latter in fact being the measure of its value.

There are certain classes of drawings—of which the Patent Office drawing is a good example—in the making of which the picture idea is predominant. Here the purpose is to illustrate mechanisms, not construct them; hence the function of the drawing is in no wise that of the working shop drawing, and as such does not fall within our discussion.

Cost of Producing Drawings. The second general element involved in producing shop drawings is their cost, as measured by the draftsman's time. It is somewhat subordinate to the first element, for the drawing must be a good one, judged by an absolute standard, whatever the time or cost necessary to produce it. Cost, however, is an important item, and cannot well be overlooked. It is inevitable that in any enterprise economy will ultimately be sought, whatever extravagance an imperative original demand may have permitted. This is as true in the production of drawings as in the case of manufactured articles of trade. Drafting-room labor is a relatively high-priced service, and the salary list easily assumes considerable proportions, so that wasteful excesses count up rapidly. One of the qualifications of proficiency invariably required for this department of shop organization is rapidity of execution. This is not as dependent upon personal traits as at first might be supposed. A man may so husband his time and

direct his efforts that he will easily distance his neighbor of more rapid motion. The latter may have less ability to make his energies count, and lack of judgment as to when just enough, and no more than enough, energy has been expended on his drawings. From the standpoint of *Utility*, the function of a drawing is fulfilled when it has reached the stage that it *completely* instructs; more time spent in elaboration is wasted, and is an unnecessary and therefore extravagant expenditure. The student must fully realize this. In his earnestness to produce finished and complete work he must constantly strive to accomplish results in the least possible time. This does not mean careless haste; far from it. A complete shop drawing cannot be made by short cuts, but through a systematic building of line on line, dimension on dimension. This is in sharp contrast to a haphazard habit of developing a drawing, first a line here and then a figure there, with no definite purpose in mind, and no hint as to when the drawing is actually completed.

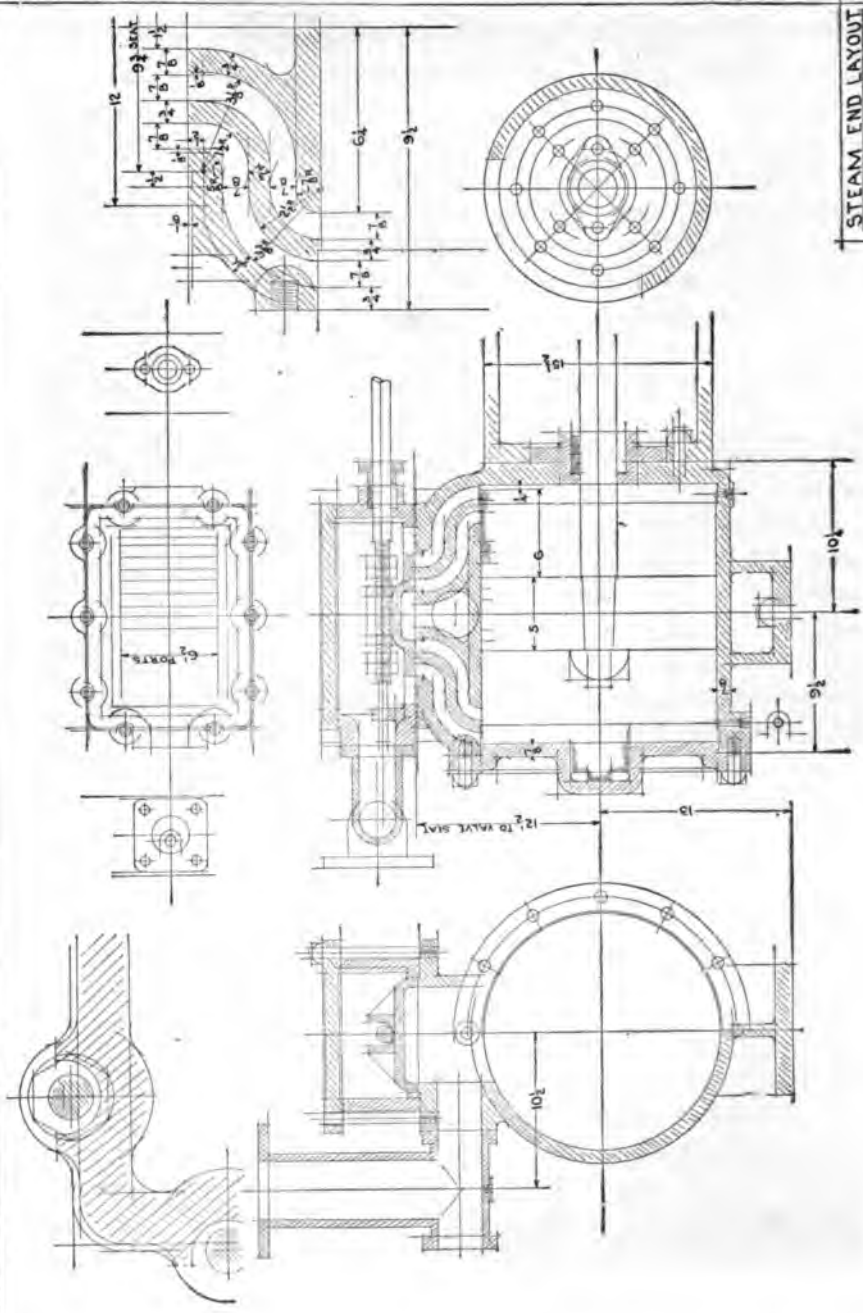
The one method constitutes the efficient draftsman who works easily, receives a high salary, and is worth it, because he wastes no time in unnecessary labor. The other marks his unfortunate brother, plodding laboriously far behind, receiving a small pittance per hour, and worth less, because he does uncalled-for labor, and loses his definiteness of purpose in a maze of unexplainable lines and figures.

A working shop drawing, commercially considered, may well be defined as being "Complete instruction from designer to workman issued at minimum expense."

This definition should be memorized by the student, and constantly kept in mind while making a drawing. The preceding pages should be re-read with this in view until the full spirit is appreciated.

The maxim as given above, if faithfully adhered to without modification, answers nearly every question that can be raised as to the excellence of a drawing. It can be used as a standard of judgment, whatever system of lines or symbols may be in vogue. It permits a draftsman to adjust himself to the rules of any shop or drawing-room, and yet produce a good drawing and satisfy his employer.

STEAM END LAYOUT
 16-81-12 DUPLEX PUMP
 AMERICAN SCHOOL OF
 CORRESPONDENCE
 BOSTON, MASS.
 SCALE 3:1



lined. The power end of the machine introduces us to the steam engine; the load end is the beginning of the engineering of pumping machinery.

Rating of Pump. A steam pump is rated by the bore of its cylinders and length of stroke, all being given in inches. A " $16 \times 8\frac{1}{2} \times 12$ pump" means that the steam cylinder is 16 inches in diameter, the water plunger $8\frac{1}{2}$ inches in diameter, and the nominal length of stroke 12 inches. These sizes are always given in the same order, beginning with the diameter of the smallest cylinder (in case there is more than one), then the diameter of water plunger, the common stroke of both being placed last. This expresses to the mechanic the rating of the pump in the clearest style and briefest language.

The pump illustrated here is designed for standard service, operating under a steam pressure not to exceed 100 pounds per square inch, water pressure not to exceed 150 pounds per square inch, and the rated capacity based on an average piston speed of 100 feet per minute being about 550 gallons. This requires that each side of the pump shall handle 275 gallons, and being double acting, shall make 100 reversals or 50 double strokes per minute.

Plate A. Steam End Layout. This plate illustrates, as nearly as reproduction can accomplish, the pencil layout of the steam end. It is the first work of the designing draftsman. The drawing as shown is exactly the type of layout which he would turn over to a detail draftsman, whose duty it would be to work up detail shop drawings therefrom.

The character of this drawing should be carefully studied. Remember that it is a layout, nothing more; also bear in mind that it is an exact, measurable working sketch. Attention is called to the sharpness of the lines, especially to the clean-cut intersections. Note the boldness, dash and businesslike style, the free-hand cross-section lines roughly put in. There is no hesitation or worry as to where the end of a line shall be, or whether it crosses other lines which it theoretically should not. The intersections are allowed to indicate the termination of lines, and the rough section lines pick out the parts and separate them clearly to the eye. There is the spirit in this layout of confident, definite and rapid action, with no thought for absolute finish in line-work, but

with every thought for absolute results as to measurable dimensions.

The data for the production of Plate A by the student are rather more complete than he would usually find in practice. Plates E, F and G show many details fully.

The steam cylinder and head, however, as shown in Plate G, are not dimensioned, and the student's problem is to produce this plate complete, with finish marks, dimensions and necessary data for a working drawing. In order to do this it is first necessary to work up Plate A with exactness, in pencil, and see that all parts go together properly. Then the detail of cylinder and head may be made separately by measurement of the layout drawing, and Plate G produced.

For this work the ordinary brown detail paper is very satisfactory. A hard lead pencil is necessary, as hard as 6H, and the point must be kept well sharpened.

There are two general rules of action in producing a drawing which give the answer to the question which oftenest confronts the beginner: "What is to be done first?" or "What is to be done next?" These rules are:

1. Draw everything that is positively known.
2. Work from the inside to the outside.

Every problem has some positive data, assumed or calculated, to start with. The first thing to do in every case is to get this data represented by lines on the paper. An expert designer has been heard to say that until he had spoiled the blankness of his sheet of paper by some lines, he could not design. There is something in this; and almost invariably the first line to draw is a horizontal center line somewhere near the middle of the sheet; draw it! Draw it at once without hesitation, and the layout is begun. We now have something about which to build.

In this case the designer would first calculate the size of the piston rod, and determine the fastening to the piston. He would then draw the rod and build a hub around it. He would next calculate the width or thickness of piston and size of packing rings, and draw the two vertical lines 5 inches apart, to indicate the piston faces. These lines would be limited by the cylinder bore, which he knows to be 16 inches; hence horizontal lines 16

inches apart, parallel to and symmetrical with the center line, are the next to be drawn. Short vertical lines indicate the location of the packing rings. As the nominal travel of the piston is to be 12 inches, the location of the piston and rings can be shown on both sides of the central vertical line at the limits of travel. A clearance must exist between the heads and the piston (in this case $\frac{1}{4}$ inch is allowed), hence the lines of the heads can be drawn, and the general inside outline of the cylinder barrel is complete.

This is all in direct application of the foregoing rules, and is so simple, natural and direct that it hardly requires such explicit statement. We have simply taken such data as we had and put it on paper, placing it where it can be seen from all sides, and where the mind is relieved of the labor of carrying it.

If the student will only appreciate this one rule and draw all he knows about the problem, he is well on his way to its solution. *Draw everything you know, and work for what you don't know*, is what these two rules say, and the first question to arise should be: "Have I drawn everything that is known about the problem?" before he asks himself or any one else: "What shall I do next?"

One other rule might be added to these two: *Keep dimensions in even figures, if possible*. This means that small fractions should be avoided. It is just as easy to bear this point in mind, and save the workman much annoyance and chance of error, as it is to disregard this matter. Even figures constitute one of the trade-marks of an expert draftsman. Of course a few small fractions, and sometimes decimals, will be necessary. Remember, however, that fractions must in every case be according to the common scale; that is, in sixteenths, thirty-seconds, sixty-fourths, etc.; never in thirds, fifths, sevenths, or such as do not occur on the common machinist's scale.

A systematic, definite mode of treatment on these lines must become a habit, so that all problems, however complicated, can be approached with confidence in the same way. It is the drawing of one line which makes clear the drawing of the next and subsequent lines; and the most serious obstacle which the student is likely to set for himself is trying to see the whole problem through from the beginning. Even an expert cannot do this, but allows the layout to develop results as he proceeds.

The details of the piston and rod being given in Plate E, the foregoing work is very easy for the student. The thickness of the barrel and heads being determined ($\frac{1}{8}$ inch in this case), the exterior outline may be partially drawn. The fixed head at the yoke end must be thicker than this, in order to receive the yoke and stuffing-box bolts without breaking through. The recesses or counterbores at either end of the cylinder should be so located that the packing rings run over the edge a little at the end of the stroke, thus preventing the wearing of a shoulder by the piston stopping in the same place every time. The counterbore should be deep enough to allow reboring the cylinder without the counterbore being touched by the tool. In this way the counterbore is retained to center the cylinder at its original location.

The size of steam ports having been calculated, they may be drawn in, the turns being made easy and as direct as possible. The height to valve seat must be kept at the lowest limit consistent with sufficient metal between and outside of the ports. As the detail of the ports might be somewhat troublesome, it is shown in an enlarged sketch for the student's benefit. Chipping or filing strips $\frac{1}{8}$ inch high are left on the port edges, which must be true, in order to finish them up easily.

The three inner ports are for exhaust, the outer ones for admission of steam. This five-ported cylinder is peculiar to the direct acting steam pump, it being a device to effect the cushioning of the piston at the end of the stroke, thus preventing the piston from striking the heads. This is necessary, since no positive limit of motion exists, as is the case in machines with crank and connecting rod.

When the edge of the piston has passed the outer edge of the exhaust port, as shown in Fig. 1, the steam, which has been exhausting through port A, is confined in space B and port C, and, being compressed by the piston, acts like a spring to retard its motion. If the point P is properly determined for a given speed, the piston will always compress the steam just enough to cause it to stop at the end of the nominal stroke; in this case, $\frac{1}{4}$ inch from the head. It is evident, however, that at different speeds the piston will have more or less power to compress the steam, and will not stop at the point desired. This causes the trouble of "short stroke," and

consequent inability to make the pump work to its full capacity. Now if we connect ports A and C by a small opening shown dotted at D, and control this opening by a plug valve operated by hand from the outside, we can let a little steam leak by into port A, thus reducing the cushion and allowing full stroke.

In order to avoid complicating the drawing, no cushion valves are shown or required to be put on by the student. They are not customary in small pumps, but might advantageously be put on the present illustration.

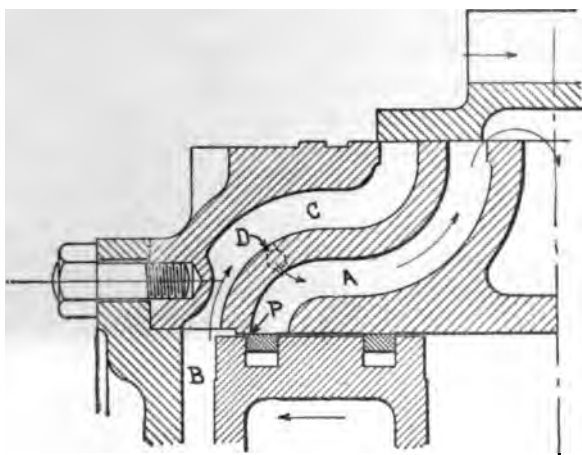


Fig. 1.

The valve seat must be a scraped surface, while the chest face need not be; hence the latter is finished $\frac{1}{8}$ inch lower. This also gives a ledge against which the steam chest fits, thus securing positive location.

The bolting of the heads and the steam chest should allow a width of packing inside of the bolts of $\frac{1}{2}$ to $\frac{5}{8}$ inch, otherwise there is danger of the steam blowing out the packing and causing leakage around the bolts. The bolts do not fill the holes, the latter being drilled large, from $\frac{1}{16}$ to $\frac{1}{8}$ inch. The spacing, if wider than 5 or 6 inches, is likely to permit springing of the flanges between the bolts, and consequent leakage. Bolts less than $\frac{5}{8}$ inch diameter are not desirable, as they can be easily twisted off with an

ordinary wrench. In this case the cylinder head takes $\frac{1}{8}$ -inch bolts, the yoke, stuffing-box and gland, $\frac{3}{4}$ -inch.

The flanges of heads and cylinders are usually from 25 per cent to 50 per cent thicker than the body of the casting.

Drips, $\frac{1}{2}$ -inch pipe tap, to be fitted with cocks, are necessary at both ends of the cylinder to readily drain the cylinder of water.

Molding of Steam Cylinder. The design is often influenced by the way in which the piece is to be cast. It often takes but a slight change of design to save many dollars in pattern making and foundry work. Hence the habit should be formed of always judging the design of a piece from the foundry standpoint. In this case it is evident that the ports and cylinder bore must be cored out, and the most obvious position of molding is to lay the cylinder on its side, the parting line of the flask being along a vertical plane running lengthwise through the middle of the cylinder. This permits the chest flanges to draw nicely, likewise the ribs on the foot, and allows the thin curving port cores to stand edgewise in the mold.

Another method of molding would be with the valve seat down. This would involve loose pieces for the chest flanges, and setting of cores for the cylinder foot. It would, however, assure sound metal beyond question at the valve seat. Spongy metal at the important wearing surfaces, the valve seat and cylinder bore, is not permissible in any case, and care in molding, and good design, is necessary for good results.

All corners must be carefully filleted, and chunks of metal must be avoided, especially where several walls or ribs join. The metal must be kept of average uniform thickness, so that the whole casting will cool uniformly.

Machining of Steam Cylinder. The boring may be done on a vertical boring mill, the heavy arm carrying the tool being thrust down unsupported into the cylinder, the latter being rotated by the table to which it is clamped. If the horizontal boring machine be used, the hole through the inside head for the stuffing box must be large enough to permit a stiff boring bar to be passed through. This allows a support at each end of the bar, to take the strain of the cut.

The plane surfaces may be finished on a reciprocating planer

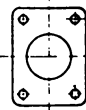
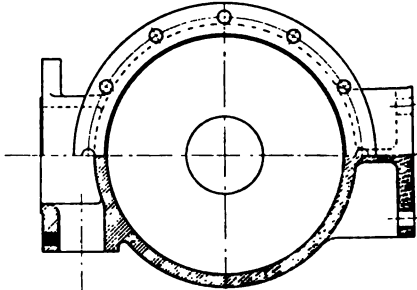
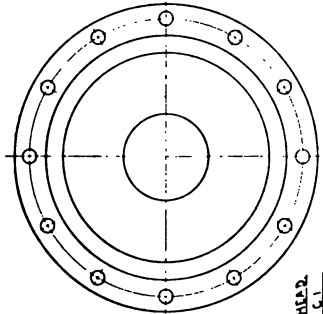
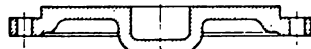
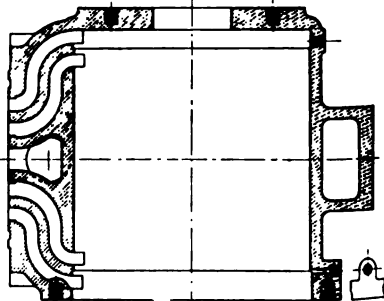
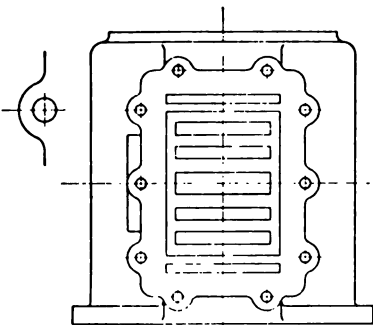
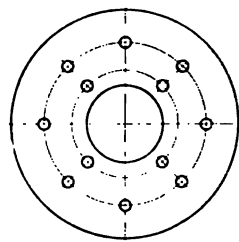
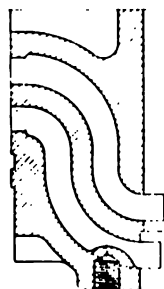
or a rotary planer. In the latter case it is desirable to keep all lugs or projections back from finished surfaces, to permit the large round head which carries the cutters to pass over them without interference.

The drilling of standard machine parts of this character is usually done through jigs, or plates carrying hardened steel bushings laid out to correspond with the holes required, and through which the drill is guided. These plates are located by some fixed line or lug on the casting, and then clamped fast, thus assuring exact duplication and rapid drilling, and avoiding the tedious laying out of the holes. In order to save changing the drill it is desirable, if possible, to maintain the same size of hole on any given surface. Of course it is not always admissible to do this.

Plate G. Steam Cylinder. After the exact and complete development of the steam-end layout, the student should be pretty thoroughly acquainted with the details of the cylinder. All the work thus far has been entirely for *his own* information, to get his ideas in visible shape, so that he himself can have a permanent record of them. This layout, however, is not in suitable form to finish up into a detail drawing. Its sketchy nature and the confusion of parts, especially if attempt were made to add dimensions, would render it somewhat difficult to be read by a workman taking it up as an unfamiliar subject. Hence it is now necessary to separately detail the parts, with the object in view of transferring, in the simplest and most direct manner, specific information to the workman which will enable him to construct the several parts. It is not enough now that the drawing be clear to the man who makes it; it must be clear, *absolutely clear*, to the shop mechanic, who has no means of knowing the designer's plans except through the information which the drawing gives on its face.

This requires that the draftsman should put himself in the workman's place, and forestall, by the explicit nature of his drawing, all possible questions which may arise in the shop. In this way only can he hope to avoid errors of construction and the continual annoyance of endless explanation of his orders.

Plate G is to be a finished drawing, and the first thing to do is to lay out the sheet. The standard sheet for details which has



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been adopted is 18 x 24 inches minimum size, with $\frac{1}{4}$ inch margins all round, so that the working space is 17 x 23 inches. The rectangle for the title is to be laid off $2\frac{1}{2}$ x 4 inches in the lower right-hand corner, and must never be altered under any circumstances. This does not mean that other sizes are wrong, but once a standard system is adopted it must be strictly adhered to, both for artistic and commercial reasons. The scale to which the drawing is to be made is indicated in the title corner of every plate.

The scales permissible for shop drawings in the United States are those readily derived from the ordinary foot rule, such as full size, 6 inches = 1 foot, 3 inches = 1 foot, $1\frac{1}{2}$ inches = 1 foot. These are the most common, most easily read from an ordinary scale, and one of these can usually be adopted. The student should learn to read these from an ordinary scale without being confined to a special graduation. To do this it is not necessary to divide each dimension by 2, 4 and 8 to get half size, quarter size, or eighth size, and then lay down the result. For half size, or 6 inches = 1 foot, $\frac{1}{2}$ inch on an ordinary rule represents 1 inch. Hence, each half inch may be read as 1 inch, and

its subdivisions accordingly, thus: $\frac{1}{2}$ inch = 1 inch. For 3 inches =

1 foot, or quarter size, $\frac{1}{4}$ inch represents 1 inch, and looks

thus: $\frac{1}{4}$ inch = 1 inch. For $1\frac{1}{2}$ inches = 1 foot, or eighth size,

$\frac{1}{8}$ inch represents 1 foot, and looks thus: $\frac{1}{8}$ inch = 1 foot. It

is very easy to get accustomed to this, and it saves much time and trouble hunting up a special scale every time.

The other allowable scales, less common, but sometimes necessary on large work, are 1 inch = 1 foot, $\frac{3}{4}$ inch = 1 foot, $\frac{1}{2}$ inch = 1 foot, $\frac{2}{3}$ inch = 1 foot, $\frac{1}{4}$ inch = 1 foot, and $\frac{1}{8}$ inch = 1 foot. To use these scales conveniently, special graduation is desirable.

The general arrangement of the sheet, number of views and approximate space occupied, should be blocked out first. This can easily be done from the original layout. In general, several cross-

sections are preferable to a single view, which involves many dotted lines. Dotted lines are very convenient for showing invisible parts of an object, but they are often abused, and the drawing of a complicated piece made indefinite and confused thereby. As already stated, a working shop drawing is solely to convey information to the workman at the least possible cost. A careful consideration of this will settle the question of the number of views necessary, their character, and the amount of dotted line work desirable.

Never let the drawing become the master; always be master of the drawing. Do not draw an extra view if no use can be seen for it. Do not put in dotted lines if the detail is completely shown without them. Full lines, or lines which show visible portions must, of course, be shown completely.

The nature of the pencil work on Plate G should be the same as on the original layout; viz., sharp, definite lines and positive intersections. Above all things learn the habit of accurate workmanship, for it will save many errors and a vast amount of time. The draftsman must check himself at every line he draws. Slight errors in scaling will often throw parts out of proper relation to each other, and interferences, which the drawing does not show, will become apparent only when the parts get into the machinist's hands.

It is dangerous practice to project across from one view to the other. It only takes a slight irregularity or spring in the T-square to vary the location of lines very perceptibly from where they should be, and once out of scale from this reason it is almost impossible to work a view with any certainty. Rather than project across from view to view, the principal lines, at least, should be scaled off on each view, and it will be found that in the end time will be saved and greater accuracy secured.

It is not economical of time to finish one view before beginning another. It is better to take some single detail of the drawing and develop it in all views, in order to study it from all sides. What is completed in one view may be found to be totally wrong when developed from another side, and the time spent on the first view will be wholly wasted. For example, in the present case the steam ports should be drawn in side elevation, end eleva-

tion and plan, and when thus completed the mind can leave them and in a similar fashion take up the study of the flanges, then the cylinder foot, and so on. Thus again the draftsman is master of his drawing, for he is continually making it tell him whether he is right or wrong. If, on the contrary, he allows himself to look at but one side at a time, and works from that standpoint alone, it may lead him into many difficulties from which he cannot readily extricate himself.

Do not be afraid to use the eraser. The draftsman who hesitates to draw until he is positive that no change will be necessary, is likely to spend the greater portion of his time in unprofitable dreams, for he is attempting the impossible. A drawing is a means, not an end; and, as has been already pointed out, it greatly assists the draftsman in clearing up many doubtful questions which the imagination alone cannot do.

A bold attack of a problem shows the quickest path to its solution, even if lines must be erased again and again. It is a sign of serious lack of ability to hesitate in the use of pencil and eraser.

Attention is called to the simple, straightforward character of Plate G. Notice the almost entire absence of dotted lines; the enlarged section through the ports, giving ample opportunity for dimensions without confusion; the use of a half end elevation and a half cross-section,—the one to make clear the flange and bolt layout; the other to show the exhaust opening, the small auxiliary views (drawn at convenient points) of the exhaust flange layout, the cylinder foot and the drip boss.

A steam cylinder is a fairly complicated casting; and it would be an easy matter, by the use of elaborate views, the dotting in of parts already completely shown, and careless line work, to rob this drawing almost entirely of its clearness and directness of illustration. *Just what is necessary* (for clearness' sake) *and no more* (for cheapness' sake), is the whole matter in a nutshell, and is what determines its shop and commercial value.

Dimensions and Letters. A good line drawing can be spoiled by poorly arranged dimensions and hasty lettering. The five principal points to be kept in mind to develop excellence in this respect are:

- (1) System.
- (2) Accuracy.
- (3) Clearness.
- (4) Completeness.
- (5) Character.

System. The habit of system in placing figures and letters on a drawing is the one element which, to a large extent, controls all the others. If the systematic habit is established early, the other requirements will be fulfilled more easily. A haphazard method will, on the contrary, just as surely prevent the successful cultivation of the ability to figure a drawing. In fact, if the haphazard habit is continued it will itself, by the dissatisfaction which it causes, soon compel the draftsman to change his occupation.

In the first place, whatever part of a machine detail is to be dimensioned, that particular part should receive attention until it has been completely figured. Do not jump from one point to another, putting in a figure here and another there. Stick to one thing until it is done.

For example, take Plate F and the simple detail of the steam pipe. Suppose we start with one of the square flanges. The first question is: "Where is this flange located?" This is answered by the dimensions 5 inches and 21-inch centers, which refer the face of the flange to the center of the pipe and the flanges to each other. The next question is: "What are the three dimensions of the flange,—length, breadth and thickness?" This is readily answered as shown on the drawing. The next question is: "What further description is necessary to completely specify the shape of the flange?" This is answered by the radius of the corners, $\frac{3}{4}$ inch R. Next, "What drilling or special feature exists in the flange?" This is answered by $\frac{1}{16}$ -inch drill, $3\frac{1}{2}$ -inch centers, and the letter *f* to denote that the face is to be finished.

The round flange of this pipe is approached and figured in the same way, except that the location of the face is preferably referred to the face of the square flange by the figure $8\frac{1}{4}$ inches, instead of to the center of the pipe, because the planer hand will more naturally use this figure.

These flanges are now to be connected by a pipe involving two sizes. The main pipe is 3 inches diameter inside, 4 inches outside, and $\frac{1}{2}$ inch thick, running into the two branches by fillets

and radii, as figured. The two branches are really one pipe, $2\frac{1}{2}$ inches inside, $3\frac{1}{2}$ inches outside, $\frac{1}{2}$ inch thick, and sweeping down into the square flanges by 4-inch radius.

This systematic method takes longer to explain than to actually execute, but it is typical of the train of thought which must be followed on all pieces, simple or complicated, in order to properly place dimensions.

In general, it may be stated that all parts of a piece must be referred either to each other, or to some common reference line, or to both. Each part so referred must then be figured as a piece by itself, and then its connections to the principal structure. Thus, figuring a machine detail involves three things:

- (1) Relative location of its parts.
- (2) Proportions of these parts.
- (3) Proportions of connecting members.

As in the original design of a piece so in the figuring of it, the draftsman must as far as possible put himself in the place of the workman, judging the methods and processes of construction and available tools. This will largely influence the arrangement of the dimensions. Of course it implies considerable experience in shop work, which some students do not possess. He can begin none too early, however, to learn to look at his work from the shop standpoint, and surely make it some better on that account.

Pieces must not only be systematically dimensioned, but regularly specified and called for by suitable titles.

A title should specify at least three things:

- (1) Name of piece.
- (2) Number wanted for one machine.
- (3) Material.

To these might be added a fourth; viz., pattern or piece number. The latter is not specified on the drawings under discussion, because systems of pattern and piece numbering are so varied that little would be gained by developing one for this special study.

These titles should always be put on in the same way, as the workmen become used to a certain system and are likely to misunderstand directions if a regular plan is not followed. A good way to arrange titles is suggested on the plates, although there are others which might be used.

Bolts are usually specified by diameter and length under the head, the length of thread being to some standard system in use by the shop, unless otherwise called for. Bolts are specified on the sheet containing the piece into which they are tapped. In the case of through bolts, tapped into neither piece, they are preferably called for in connection with the principal member.

Accuracy. Of course the dimensions on a drawing must be accurate. It is, however, a very easy matter to make errors. To insure accuracy a figure must *never* be put down carelessly, and a constant watch must be kept that scaled figures add up to over-all dimensions. It will not do to rely on scaling alone, as a very slight variation from exact scale may throw two dimensions out with each other. In spite of all the care that can be exercised errors will creep in, and a final thorough checking must be given a drawing before it is pronounced complete. A good rule to follow in checking up is to "assume everything wrong until it is proved to be right."

Clearness. As in the line drawing itself, there must be absolute clearness of instruction by the dimensions. Any doubt as to what a figure is, or what it means, rules out that figure as part of the drawing. If a piece is made wrong because doubt of this character is transmitted to the workman, the draftsman is always held responsible for the error.

Figures should, in all cases, be placed where they can be most clearly read. They should be bunched on a single view as far as possible, but not when greater clearness demands that another view be used. It hinders the reading of a drawing materially if the eye is forced to jump over large spaces of the sheet from view to view, to catch the several dimensions of a small detail. Usually it is easy to so group figures as to avoid this.

It is a good plan to keep dimensions off the body of the drawing, when it can be done so conveniently. It is not worth while, however, to go out of one's way to do this, as figures in the open spaces of a detail do not at all destroy its clearness.

Extended notes on a drawing to make it clear should not be required, but they should be used without hesitation if any doubt exists. An explicit note of instruction is the final resource for clearness when the art of drawing fails of its purpose, as it sometimes does.

Completeness. A detail is completely dimensioned when it shows *all* the figures necessary for the workman. Anything short of this is incompleteness. As modern shops hold the draftsman solely responsible for the design, the mechanic is not allowed to modify it by filling in any omitted dimensions. The only way to be sure that all the dimensions are on is to systematically go all round a piece inside and out, according to the method suggested under the paragraph on "System."

It is a good plan to always bear in mind that not only the machinist is to use the drawing, but also the pattern maker. For the benefit of the latter, special attention is desirable in figuring the cores. This saves him some addition and subtraction. In general, it has been found that less chance of error exists if mathematical work is not required of the shopman, all necessary data being furnished on the face of the drawing.

Character. By character in figures and letters is meant uniform style, height and slope, and a certain boldness peculiar to the work of the expert draftsman. The last is difficult for the novice to acquire. The student should not be discouraged because his efforts do not look like impressions from printers' type. Artistic excellence is the result of long experience, but is based on character. If the student can once get character into his work, the artistic feature will, with careful and constant practice, gradually develop. It is safe to say that there is no one element of a drawing which more positively stamps it as the work of an amateur than the character of the lettering, and every attention should be paid to getting out of the apprenticeship stage in this respect. Freehand lettering only is permitted in the drawings illustrated herewith. Ruled letters are seldom found on any working drawings, as the element of time involved is so great that few shops are willing to pay for it.

Uniform style requires that if capitals only are used in titles, they only must be used in notes and elsewhere on the drawing. If lower-case letters are used, they must be used in every part of the drawing. One style should not be mixed with another. The height of the letters should be limited by two horizontal lines, and though practice may render the upper line unnecessary, it takes but an instant to draw it, and uniform height is then assured. A good

height for titles of details such as are illustrated is $\frac{5}{32}$ inch. The height once chosen should be adhered to throughout the whole set. A medium, not a hard, grade of pencil (3H) will give the hand greater freedom. A great temptation exists to omit titles from the pencil drawing, simply inking them on the tracing. This is false economy of time, for in the end it will be found that enough time will be saved by the certainty with which the tracing can be made to more than pay for the labor on the pencil drawing. Again, it permits the tracing, in regular shop practice, to be made by cheaper labor than that which produced the pencil drawing.

Uniform slope is most easily acquired by the use of guide lines put in at frequent intervals. A small wooden triangle can be made, giving the required angle. The angle of the letters shown on the plates is 9 degrees, or about 1 inch slope in 6 inches. The question as to whether letters should incline backwards, forwards, or stand vertical, does not enter this discussion. Character is not affected by the slope. The student may choose whatever comes most natural to him, but having chosen, the character of his work will be spoiled if he varies it. The most difficult of the three is the vertical style; hence most draftsmen incline their letters. The backward slope is used on the plates of this shop drawing paper, thus giving the student opportunity to compare with plates in the earlier books, and follow his preference.

The effect of change of style, height and slope is shown in Figs. 2, 3 and 4, respectively. Attention is called to Fig. 5, which is a sample title, in which these points are corrected.

Principal Titles. The principal title of a drawing should contain at least seven items:

- (1) Name of principal details shown.
- (2) Name of machine.
- (3) Firm name and location.
- (4) Scale of drawing.
- (5) Date of completion.
- (6) Draftsman's signature.
- (7) Filing number.

To these are often added others, but for purposes of filing and reference the above at least *must* be put on. The filing number may or may not be put in the title frame, but it is really a part of it. It is often put in the margin below the title.

An arrangement of title should be established and then followed exactly, without variation either as to location on sheet or detail make-up. Abbreviated words are always permissible in titles, provided the meaning is clear. Special care must be taken in punctuation, however, as a title, whether abbreviated or not, has an unfinished appearance if the periods, commas and other necessary punctuation marks are not included.

STEAM CYLINDER
16-8½-12 Duplex Pump.

Fig. 2.

STEAM CYLINDER
16-8½-12 DUPLEX PUMP

Fig. 3.

The sample title illustrated in Fig. 5 indicates the arrangement chosen for the drawings of

STEAM CYLINDER
16-8½-12 DUPLEX PUMP

Fig. 4.

Part IV. Note that it is necessary in this special case to add an extra subject to the seven given above; viz., the residence of the student draftsman.

This style of title must be put with care on every drawing, even on the rough pencil layouts. In the latter case it may of course be left in pencil, as the rough layouts are not to be inked.

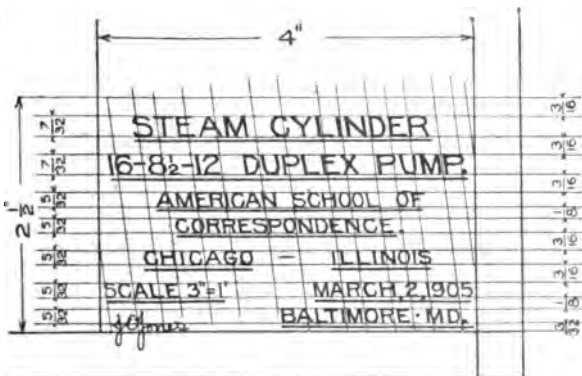


Fig. 5.

Inking and Tracing. Both bond paper and tracing cloth are used in business practice for finished drawings. It is desirable to

keep a stock of both in any drawing office, so that either may be used as occasion requires. Bond paper stretched on the board gives a beautiful surface to take the ink, and very handsome and effective detail or assembled drawings can thus be produced.

Changes are not quite as readily made on bond paper as on tracing cloth, and it takes a little longer to make the blue print. In other ways the bond paper is not quite as flexible to use as the tracing cloth. However, one must be guided entirely by shop conditions to settle the question of preference. As the tracing cloth is generally used, and suits the purpose of the student better, it will be required in this work.

The inking should be done on the *rough* side of the cloth. One reason for choosing this side is that as the cloth tends to curl under toward the glazed side, the drawing as it lies right side up will tend to straighten itself. This seems to be a small point, but it is a very important advantage for filing and for the convenience of those who are to handle the drawings. Also the rough side takes colors and inks better than the glazed side. To trace on the glazed side is not wrong, for it is often done, but it possesses no advantages of its own, and has the disadvantage mentioned above.

Chalk dust scattered over the surface of the cloth after it is tacked down will remove the slightly greasy coating which prevents the ink from flowing well from the pen. This is always necessary if the glazed side be used, and usually for the rough side. The chalk must be carefully removed from the cloth before inking.

The first step in inking is to draw the center lines. Remember that *accurate intersections* are of the utmost importance. No circle is complete without two intersecting lines, preferably at 90 degrees, to determine its center, and these lines should be inked before the circle. When this is done a definite point exists for the needle point of the compasses. If the circle is drawn first the needle point may not be placed accurately at the center on the pencil drawing beneath, and the location be thrown out.

Likewise the principal center lines of pieces, the lines around which the pencil drawing was built up, should be at once put in.

The main body of the drawing, the full lines, should be taken next. In general, circles and arcs should be inked first, but there

are cases where it is easier to run the arcs into the straight lines than to match the straight lines to the arcs. They are exceptions, however, and can be judged only as the case arises.

Straight lines, horizontal and vertical, should be inked with the T-square and triangle *in position*. It is a common practice to dispense with the use of the T-square entirely in inking in, using the triangle to match the lines to the arcs already drawn. A necessity for this implies very poor work on the arcs, for with any reasonable care true horizontal and vertical lines will match the arcs all right. With regard to time required, the accuracy with which the T-square may be brought up to a line, or the triangle set on the T-square, more than makes up for the time gained in even an approximate setting of the triangle without a guide. It is just as easy to cultivate the habit of holding the T-square and triangle with the left hand and the pen with the right, and draw an exact line, as to lapse into the other method, which is not workmanlike.

The lines of the body of the drawing depend for their width upon the size of the detail. For a large piece they may be $\frac{1}{32}$ inch wide, and the shade lines $\frac{3}{64}$ inch. For a small detail such widths would be too great. Remember that *contrast* is the principal aim, and to produce it is the only reason why we use different kinds of lines on a drawing. Hence the greatest care must be exercised to prevent body lines from becoming confused with center or dimension lines, and *vice versa*. Also thick lines are desirable for the production of a bold blue-print.

Shade lines are shown on Plates I, K and N only. They are put on according to principles already explained. They certainly improve the drawing from an artistic standpoint, and the student should know how to put them on when desired. Whether or not it is desirable to adopt them on all working drawings is not the purpose of this book to decide, or even discuss. Almost always drawings can be made perfectly clear without them, and are so made and satisfactorily used in probably the majority of shops. Some shops are willing to pay for the extra time necessary to put on shade lines; this, however, is purely their own investment.

Cross-section lines are usually drawn at an angle of 45 degrees with the horizontal, and on sections which are adjacent

to each other the slope should be in different directions. If three or more sections come together the width between section lines can be so changed as to indicate clearly the different parts. An example of this is shown in Fig. 6.

The spacing of section lines must not be too fine, rarely closer than $\frac{1}{16}$ inch, more often from $\frac{3}{32}$ to $\frac{1}{8}$ inch, else the labor involved is too great and uniformity practically impossible. It is a waste of time to rule in section lines on the pencil drawing; they may be sketched in freehand, as shown on the original layout of the steam cylinder. Even spacing concerns the tracing alone, and the student should train his eye to regularity as he traces. The thickness of section lines may be intermediate between that of center lines and body lines of the drawing.

Inking Dimensions and Letters. Extension lines may be dotted, as explained in Part III, or they may be fine, full lines, the latter method being illustrated in the series of pump plates in this paper. Dimension lines are also often made fine, full lines. If these lines are made full they should be made as fine as it is possible to draw them and still have them firm, clear lines. The same width should be used as for center lines.

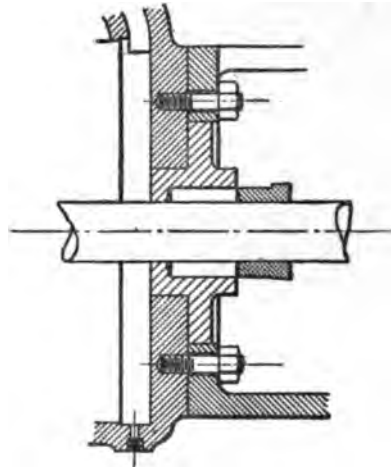


Fig. 6.

Character in inked figures and letters is more difficult to attain than in pencil work. In the first place a pen suitable to the style of drawing is necessary. A civil engineer's fine mapping pen, which gives character to his drawing, is not desirable in producing the bold character of a machine drawing. For the latter choose a rather stiff, blunt pen which is not "scratchy," but runs smoothly, making a line of uniform width. A pen with a round, or ball-shaped nib, recently put on the market, answers the purpose well for ordinary details. A bold, free stroke should be made with the idea of producing a smooth, even line, finished

at the first trial. The hesitating uncertainty of the beginner's hand produces a "shaky" letter, and going over a letter or figure twice or more to smooth it up usually makes it worse.

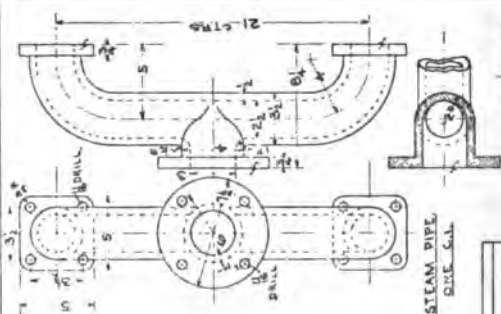
Figures and letters which are broad in proportion to height are easier to make, and have more character. It should never for a moment be forgotten that uniform *height* and *slope* carefully followed will develop character and quickly lead to artistic excellence.

Foot and inch marks are often put after figures according to the common usage. In cases where feet and inches are expressed, thus: 3' — 6", or 4' — 0", they are, of course, absolutely necessary, and the dash between the figures must be very positively indicated. In cases of inch dimensions alone the marks may be put on if desired, but where there can be no doubt that inches, and not feet, are meant, the inch marks are not necessary. This practice is followed on the plates of this paper.

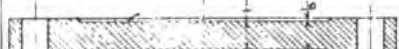
Abbreviations. A list of the most common abbreviations in use on working drawings follows. This list has been adopted for the plates in Part IV:

F. A. O.	finished all over.
f.	finished surface.
R.	radius.
D.	diameter.
R. H.	right hand.
L. H.	left hand.
P. R.	piston rod.
P. TAP.	pipe tap.
CTRS.	centers.
C. I.	cast iron.
S. C.	steel casting.
Bz.	bronze.
C. R. S.	cold rolled steel.
T. S.	tool steel.
O. H. S.	open hearth steel.
W. I.	wrought iron.

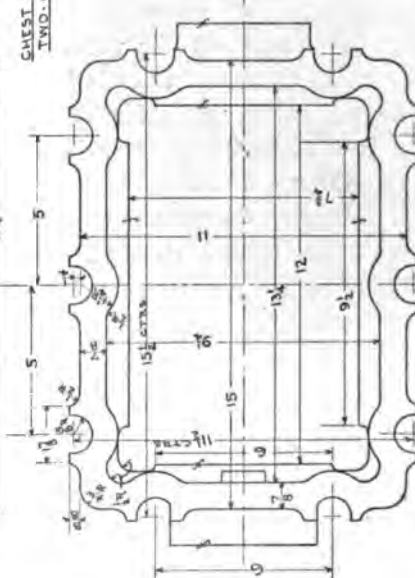
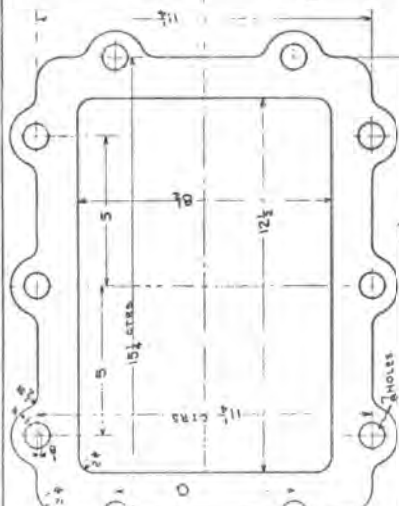
Plate E. Piston Rod and Valve Stem. The piston is of the one-piece box type, with sprung-in rings. The width is reduced to $4\frac{7}{8}$ inches at the outside, so that if the piston strikes the cylinder heads it will not tend to spring and break off the narrow ridge of metal outside of the packing ring. The piston rod is fastened to the piston on a taper drawn in by a nut, and the



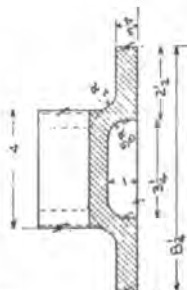
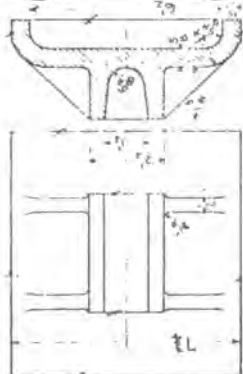
STEAM PIPE
ONE C.L.



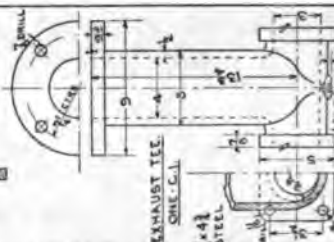
CHEST COVER
TWO C.L.



STEAM CHEST
TWO C.L.



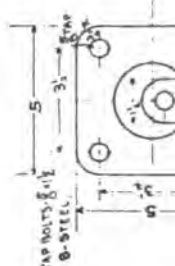
SLIDE VALVE
TWO C.L.



EXHAUST TEE
ONE C.L.



GLAND
TWO C.L.

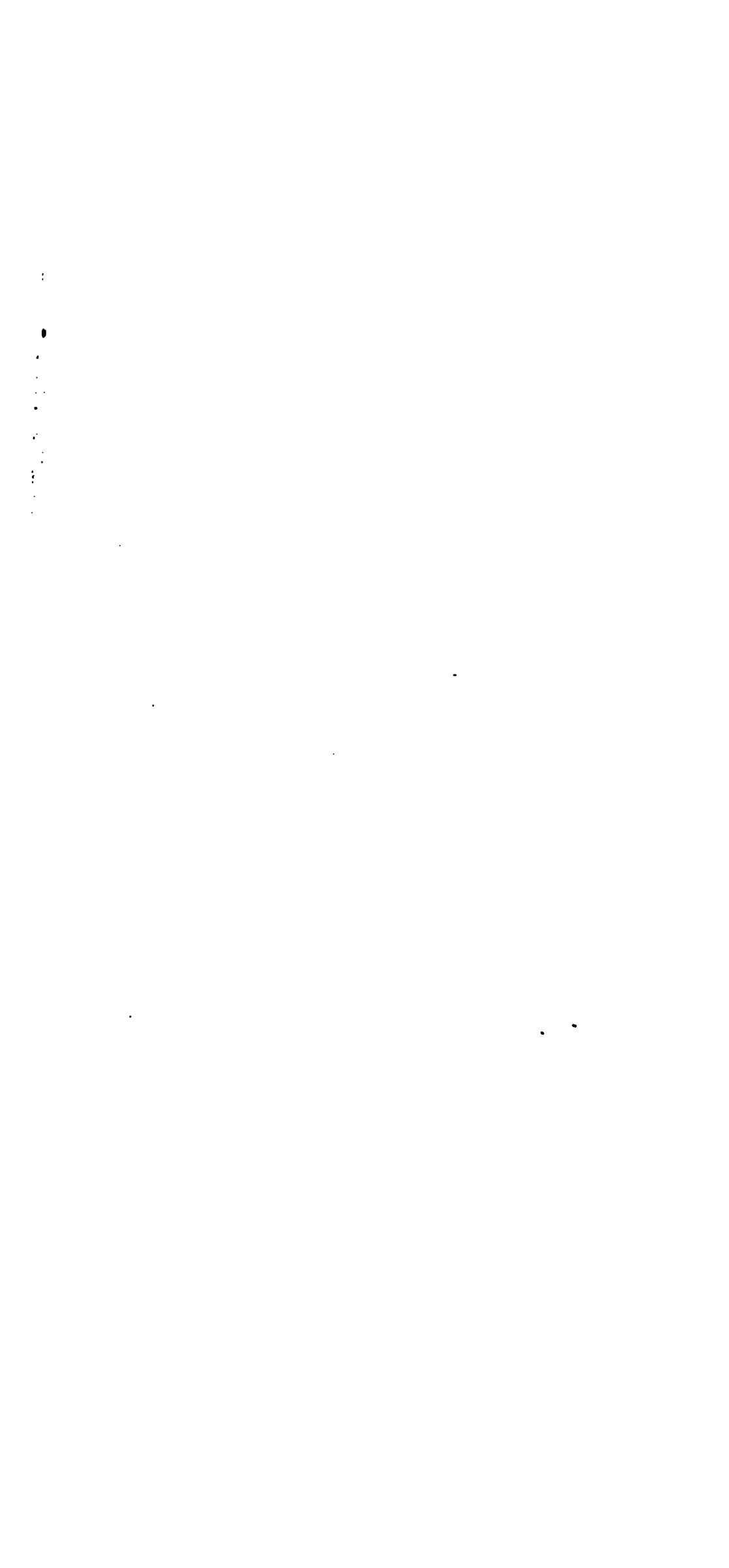


TAP HOLE
ONE C.L.

STM. CHEST 1/2 VALVE.
16-87-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE



THE AMERICAN COMPOUND PUMP.
American Steam Pump Co.



The valve is what is known as a "square" slide valve. This means that when the valve is placed central on the ports its working edges are "square" with the ports; that is, in exact line with them. If the valve be moved either way from this position, the slightest travel will admit steam to one end of the cylinder and exhaust it from the other. (See Plate A.) Another way of stating this is to say that a "square" slide valve is a slide valve without "lap."

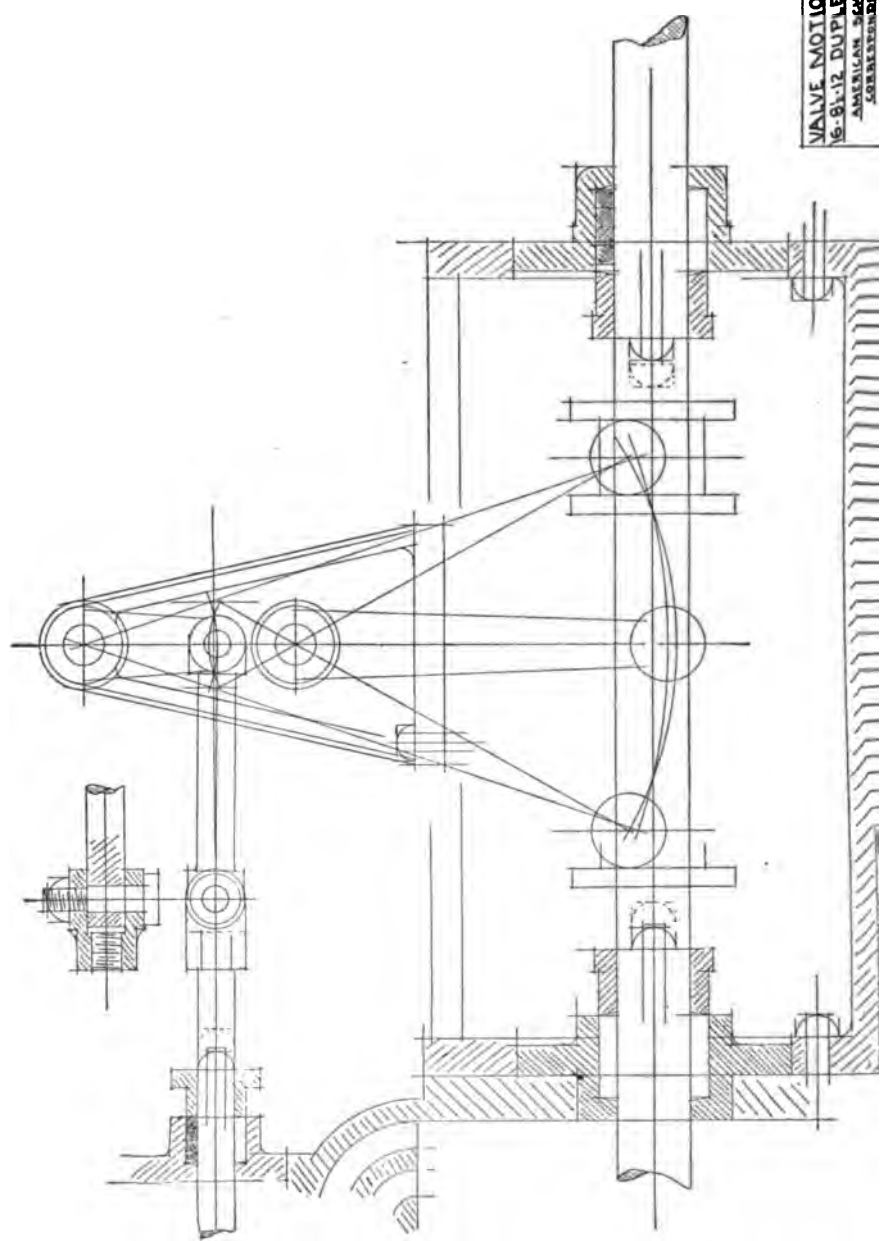
The valve is driven from the valve stem by the striking of the nuts against the lug on its top. Since the valve is already guided on its edges by the steam-chest flange, the valve stem, to avoid springing, must be perfectly free in the slot cast for it, as is shown by the $\frac{5}{8}$ -inch radius of the bottom, the stem being 1 inch in diameter.

The steam-pipe flange is made square to keep the height of the chest as low as possible. The radius of the bend should be ample; in this case 4 inches is considered sufficient.

The exhaust tee must have its upper flange high enough so that the chest cover can be lifted and slipped off the studs without interfering with it. The lower flanges should be made wide enough to permit the tap bolts to be put in without striking the 4-inch vertical pipe, 5-inch centers being necessary. The $\frac{1}{4}$ -inch drip-cock, as located, readily drains the steam chest and exhaust passage of both cylinders, as well as the exhaust tee.

Molding. It is evident that the steam chest will be molded in the position shown on the drawing. The parting line of the mold will be through the centers of the steam-pipe opening and the stuffing-box. These holes must be cored out. The main body of the chest could be made to leave its own core, but it may not be made in this way. It may be cheaper to fashion the pattern solid, and make one large core-box for the inside. In this way the pattern will probably hold its shape better and require less repairs, than if it were made in green sand. The core-box will be an extra piece to make, but it probably will cost no more than to carve out the inside of the pattern, and is a rather more substantial job when done. The molding can be satisfactorily done by either method, shop conditions being the controlling element. As far as the labor of molding alone is concerned, the first method is probably easier, as it saves handling large cores.

VALVE MOTION LAYOUT
16-8-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE

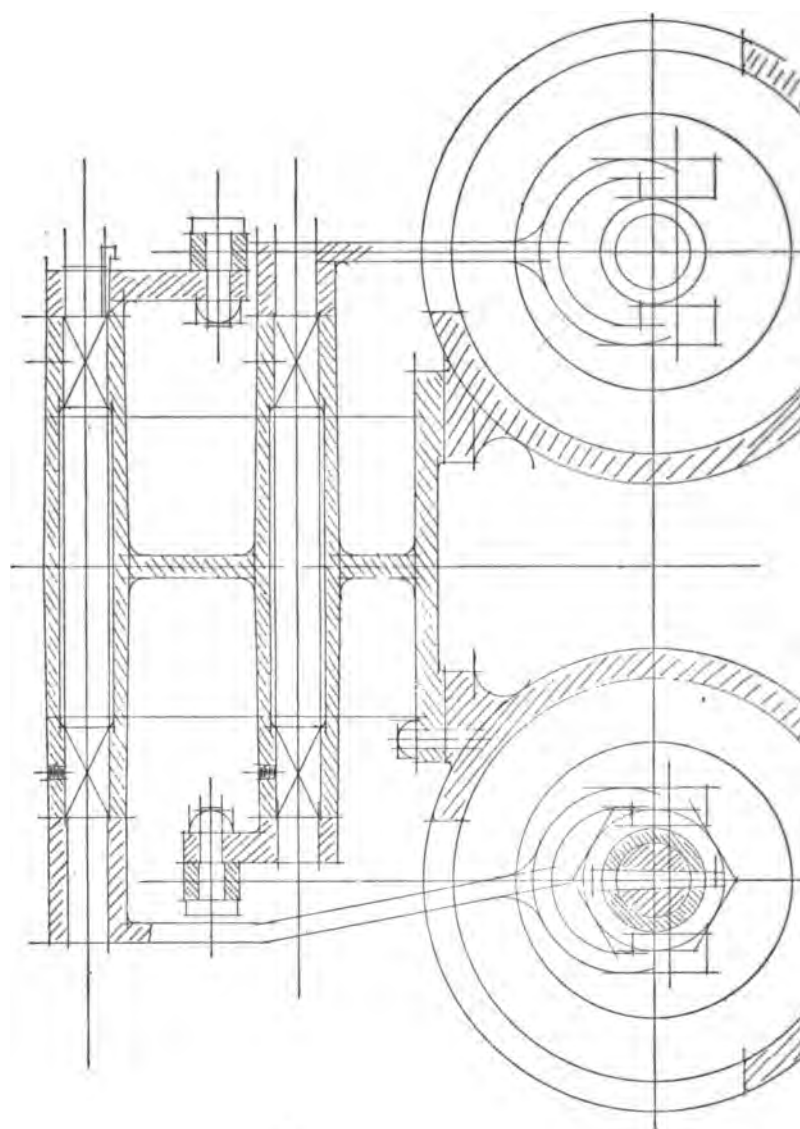


The other parts in Plate F are very simple in their molding, and require no special attention.

Machining. Most of the surface work on this plate is adapted to the planer. The slide valve may, perhaps, if finished in lots of considerable number, be more satisfactorily handled on the milling machine. The final finish of the face of the valve must be a scraped fit to its seat.

The drilling of the cover and pipe flanges is to actual layout on the casting, or preferably, through jig plates. A templet for laying-out is at least desirable, even though the expense of a jig plate be not deemed necessary.

Plates C and D. Valve Motion Layout. These plates represent the layout of the valve motion, and are necessary in order to find the length of the levers and rocker arms. It will be noticed in Plate D that the valve stem of one side of the pump is controlled by the movement of the piston-rod of the other side, the proper direction of motion being given to the valve by placing the rocker shaft above or below the valve stem as required. By reference to Plate A it will be further noticed that the nuts on the valve stem inside the chest, which abut against the faces of the lug on the valve, do not rest against the faces of the lug in the position shown, but have considerable lost motion. This lost motion is one of the essential features of the valve motion of a duplex pump, and permits the valve to remain at rest for a short period at the end of the stroke, though the valve stem may have reversed its motion and begun its return stroke. When this lost motion is taken up by the movement of the stem and the nuts abut against the lug on the valve, the valve will move, and from this point to the end of the stroke be positively controlled by the motion of the stem. At the end of the stroke the stem will reverse, when the lost motion will again permit the valve to rest for the same period as at the other end, and then move on as before. The time of rest of the valve, and consequently the pistons and plungers, is approximately one-third the period of the stroke. This means that the piston on one side travels one-third of its stroke before it picks up, through the valve levers, the valve on the other side. During the second third of its travel it is bringing the



valve to the point of opening. During the last third of its travel it is opening the port, wider and wider, to steam. Thus the opposite piston will start when the first piston has covered two-thirds of its stroke, and there will be only one-third of the stroke when both pistons are moving at the same time.

This relative period of rest to motion is not always made in this exact ratio, but is at least approximate to it. The period of rest at the end of the stroke is to allow the water end to adjust itself quietly to the reversal of motion about to take place at the end of the stroke. When the plunger stops, the water valves must be given time to seat themselves, and the flow of water through the passages checked. It is much easier to start the flow in the opposite direction if the reversal of plunger motion is not instantaneous. Hence for handling long columns of water, which, once in motion, tend by considerable energy to remain in motion, the duplex pump by this peculiar delayed action has been found to be well suited.

It will be found that for complete uncovering of port, and motion divisible into thirds as described, the travel of the valve stem should be three times the width of port, or $3 \times \frac{7}{8}$ inch = $2\frac{5}{8}$ inches. A little more than this is allowed, and the travel made $2\frac{7}{8}$ inches in this case. Referring to Plate C, this distance is laid off as shown by the two limiting vertical lines across the line of the valve stem, the central vertical line of mid-position being drawn. The problem then is to find such centers for the rocker arms that the travel of the piston-rod spool will, through proper leverage, produce travel of the valve stem between these two vertical lines. This can readily be done by a few trials, the only requirement for this case being that the extremes of the arc of swing of both piston-rod lever and rocker arm shall be equally above and below the center of piston rod and valve stem respectively. The greatest possible travel of the piston-rod spool, $12\frac{1}{2}$ inches, is usually laid out in this case, not the nominal 12 inches.

From this layout the lengths of the levers and arms may be scaled off for the detail drawing, also the location of the rocker-arm centers. The student has the former given him on Plate K, but the latter, which is necessary for the development of Plate L, must be determined by his own layout. Plate D must also be



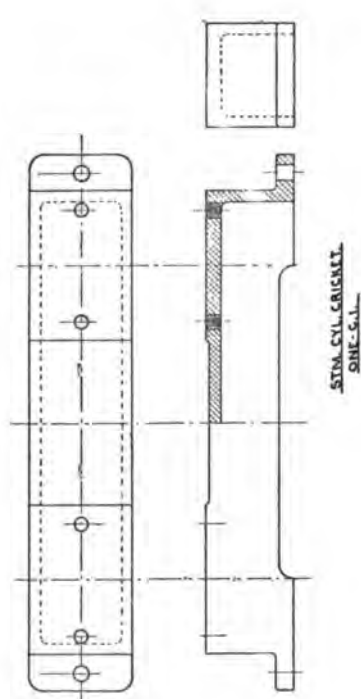
laid out before developing the cross-section of the valve bracket.

The design of stuffing boxes for both steam and water ends, and the length of the yoke, should be determined next. A safe method of assuming clearance between the spool and the gland studs at the end of the stroke, is to imagine that the gland stud nuts have accidentally worked off the studs, so that they are about to drop. They are thus shown by dotted lines on Plate C. A good clearance, say $\frac{1}{4}$ inch to $\frac{1}{2}$ inch, is then allowed, and the gland drawn in. The length of the gland is determined by the number of rings of packing necessary in the stuffing box: it is usually provided that the gland may compress the packing to about one-half its original depth before bringing up against the face of the box. Packing $\frac{5}{8}$ inch square will do for this size of piston rod, hence the faces of the yoke are easily determined, and its detail, with the stuffing boxes, proceeded with as on Plate L. The length of yoke may be brought to an even figure; and proceeding on the above plan the length can be conveniently made in even inches without any fractions; viz., 28 inches.

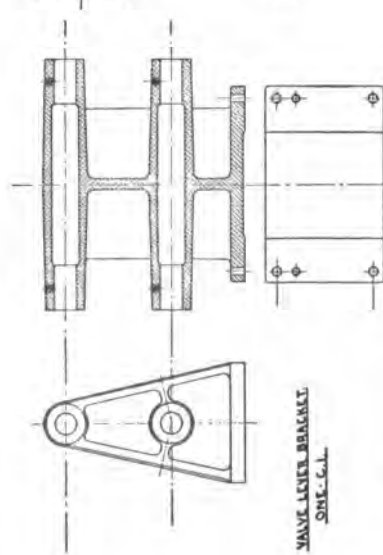
It will be noticed that the stuffing-box flanges serve to center the yoke in line with the steam and water cylinders. This is a desirable feature of construction, and forms a simple and easy method for lining up the steam and water ends.

Plate K. Valve Motion Details. The piston-rod levers on this plate are specified to be steel forgings. Forgings of this kind are expensive, but are light, neat and reliable for the important service which they have to perform. Castings, whether steel or iron, are much cheaper, and perhaps more commonly used for this detail. When sound they are equally serviceable, though of more clumsy proportions; but the danger in castings of this form is the existence of hidden flaws or pockets, which frequently occur at the points where the hub or the fork joins the arm. These flaws cannot be readily detected from the outside, and breakage may occur at some critical time, when the disability of the pump may be a serious matter.

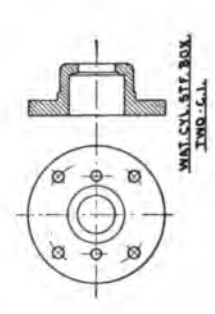
The use of shade lines is illustrated on this plate. The increased artistic effect is noticeable, but it would seem that, absolute clearness would still exist, even if shade lines were not used.



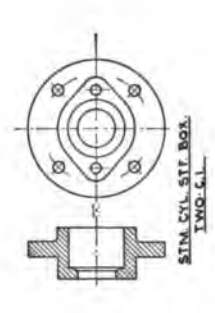
STEAM CYL. CRANK
ONE C.L.



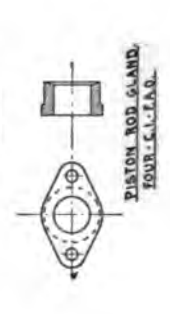
VALVE LEVER BRACKET
ONE C.L.



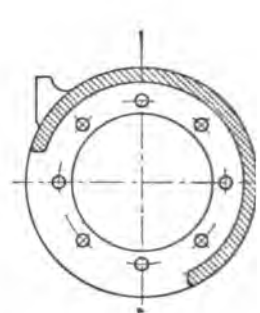
WATER CYL. STE. BOX
TWO C.L.



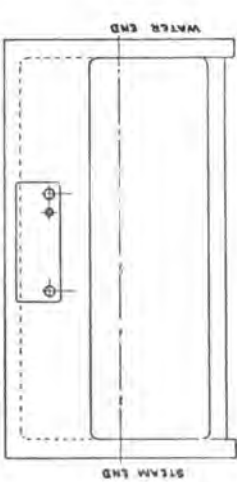
STEAM CYL. STE. BOX
TWO C.L.



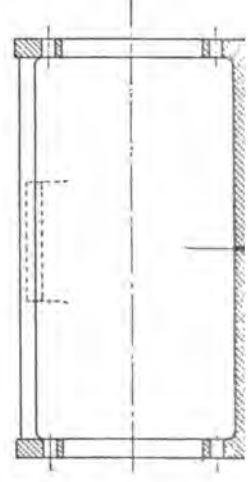
PISTON ROD GLAND
FOUR C.L.



YOKE
ONE C.L.



STEAM END
ONE C.L.



WATER END
ONE C.L.

It will be noticed that on the detail of the "link pin" two of the dimensions have a short "wavy" line beneath the figures. This is one of the several ways of indicating that the dimension is "out of scale." Some draftsmen use a straight dash beneath the figure; some draw a circle about it; some print after the figure, "out of scale." Although workmen are not allowed to scale drawings, but are required to "work to figures only," yet for general safety's sake, and for the sake of the draftsmen who consult the drawings frequently, attention must be called to any variation of the figure from the measured distance on the drawing. Nothing makes a workman, or any one else who reads a shop drawing, lose confidence in it more quickly than to discover that it does not "scale"; but when no indication exists that the draftsman himself is aware of it, then every dimension is viewed with doubt and hesitation, and the drawing becomes practically worthless.

Dimensions seldom should be out of scale; but if they are, through error or necessary change, a carefully worded note should be added.

Molding and Machining. No special features of molding or machining are noteworthy on Plate K.

Plate L. Yoke, Stuffing-boxes, Bracket, etc. Having worked up the layouts of Plates C and D, the student has enough information to proceed with Plate L. This, like Plate G, is without dimensions, the student's work being to make the drawing and fill in the necessary shop data.

The valve-lever bracket is bolted down to its lug on the yoke through holes larger than the bolt, thus permitting slight adjustment. When the proper location is determined, the bracket is positively fixed in position by two dowels, $\frac{1}{2}$ inch in diameter. The holes in both bracket and yoke are drilled through both pieces at the same operation. This very common method of fixing bolted parts of machinery in absolute position not only assures firmness, but also in case of removal, permits the part to be readily and positively replaced in its exact original position.

If possible, the steam cylinder cricket should be of such height that the stone or brick work upon which it rests shall be at the same level as that beneath the water cylinder. The tapped

holes in the top surface receive bolts from the cylinder foot. These bolts are often used only for shipping purposes, the cylinder foot when the pump is set up being allowed to slide freely on the cricket, thus permitting free expansion and contraction. In such cases the water end is rigidly fastened to the foundation by holding down bolts.

Molding and Machining. The valve lever-bracket would most naturally be molded with the axes of the shafts vertical, the parting line of the mold being the center line of the middle web. This makes quite a long "draw" for the shaft bosses, but the ample taper on the outside overcomes this difficulty. The space between the side webs leaves its own core. The shaft cores stand on end in the mold, which is the best position for strength and stability.

Another method is to have the parting line of the mold on the vertical center line of the bracket, as shown in the end view. In this case the bracket would be cast on its side, and cores must be set for each side of the middle web. The shaft cores are set as easily as before, but in this case lie flat. As with the steam chest, each method has its advantages, which depend largely upon existing conditions. As cored work is generally avoided whenever possible, the first method would probably be chosen.

The shaft bosses are "chamber-cored," to save labor in boring, the bearing surface for the shaft being only a short distance at the ends. The chamber-core diameter should be enough larger than the shaft so that by no possibility can the cutter run into the rough scale, even if the hole be bored slightly out of line. If it should do this, the labor of caring for the cutters more than offsets the attempted saving of labor.

The yoke is simply a barrel open at each end, and with a piece cut out of its side. The inside evidently must be cored out, and the core is satisfactorily supported at the ends on its horizontal axis. The parting line of the mold may be either the vertical or horizontal axis of the end view, the only difference being that in one case the ledge for the valve bracket will "draw," and in the other case it must be loose on the pattern and "pulled in" after the main pattern is drawn.

The cricket and stuffing boxes present no difficulties. The

bore of the stuffing boxes and glands should be from $\frac{1}{32}$ inch to $\frac{1}{16}$ inch larger than the rod, to allow the fit to be entirely between the rod and the packing.

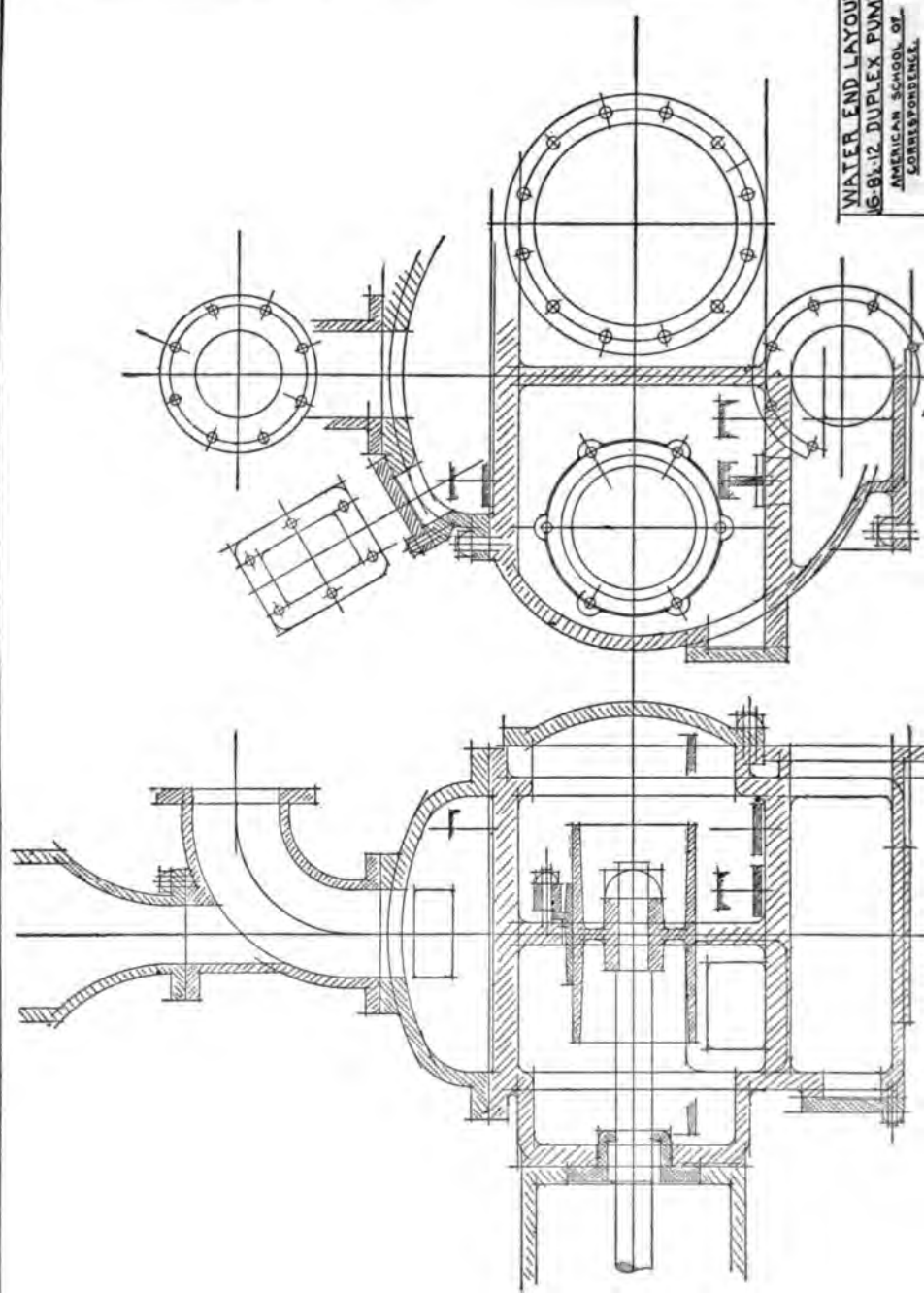
The horizontal boring machine with a double facing head is adapted to boring and facing the yoke flanges. The drilling is accomplished as before by templet or jig.

Attention is called to the tapped holes for oil or grease cups on the valve-lever bracket. The holes on the lower boss cannot be drilled strictly as shown, because the drill shank will not clear the upper boss. They should be swung around the boss at such an angle as will allow the drill to clear. This is a good instance of the common error of drawing details which cannot be made, and constant watch must be kept to avoid such mistakes.

Plate B. Water End Layout. As in the preceding work, Plates H and I being given in full detail offer a good start for the development of the water cylinder, which is the purpose of Plate B. As before, work should begin at the inside and progress outwards. Thus the piston rod with its nut should be drawn first, the hub of the plunger built around it, then the plunger barrel, the bushing, and ring to clamp the bushing. The limits of the plunger travel should be sketched in, and the valve outline shown in order to determine clearances. The progress of Plate B is on exactly the same basis as that stated in detail for the steam cylinder layout; hence it need not be repeated.

The points controlling the design of the water end must, however, be studied to enable the student to work intelligently. The fit of the rod into the plunger hub is loose, $\frac{1}{16}$ -inch play being allowed, in order to permit the plunger to be guided solely by its bushing, and thus be independent of any change of alignment of the piston rod.

The relative length of plunger and bushing should allow the end of the plunger to overrun the edge of the bushing at the termination of the stroke, to prevent the formation of a shoulder. The bushing is made of brass because of the better bearing of the two dissimilar metals, brass and iron. Of course there is no lubrication except the water, and the dissimilar metals tend to "cut" less than if both were alike. The brass bushing also prevents the plunger from "rusting in" in case of long periods of



WATER END LAYOUT
16-B-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE.

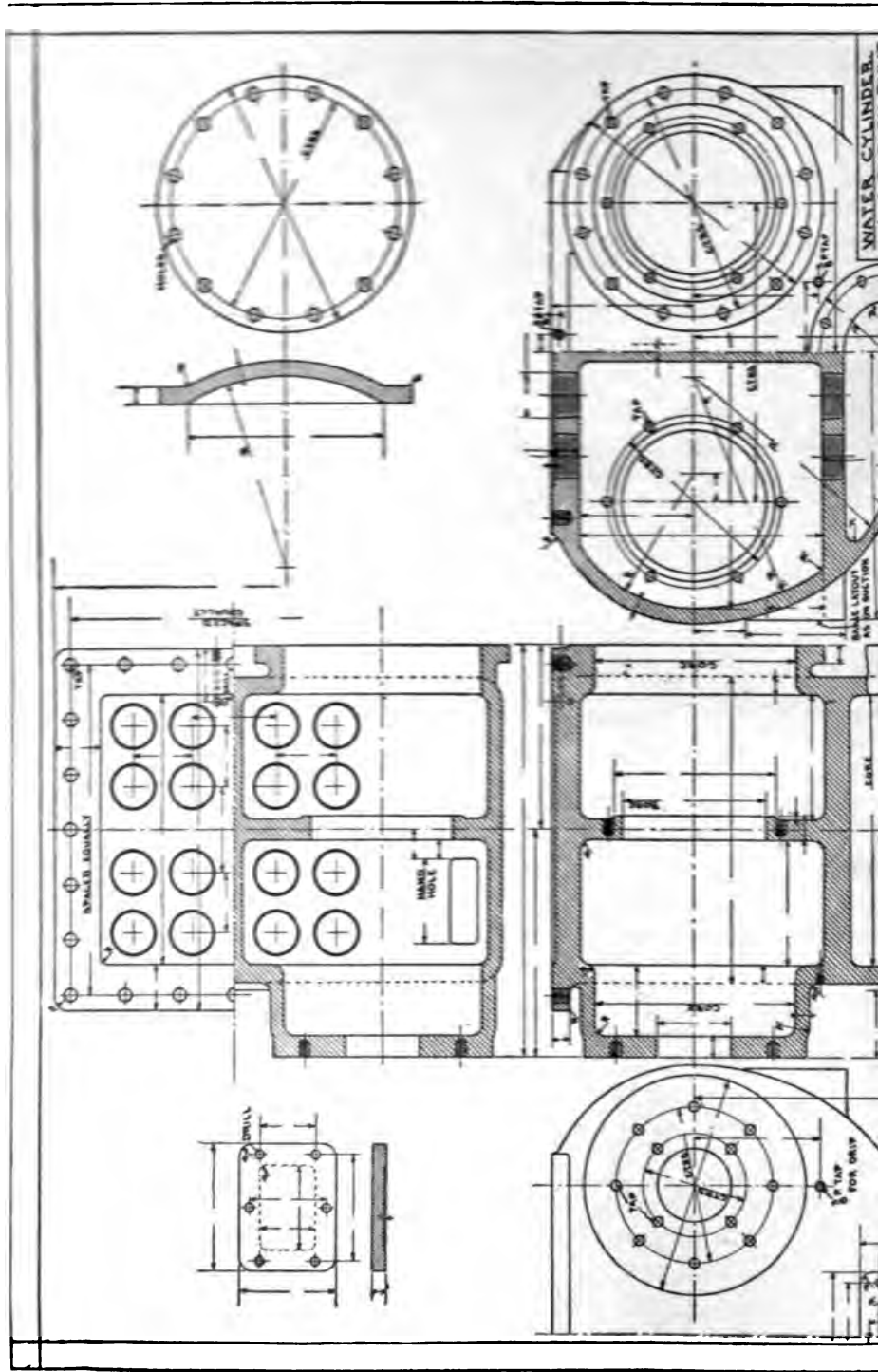
disuse. The bushing being of expensive material is made as light as possible, hence it has no stiffness of its own. Therefore it is reinforced by a deep cast-iron ring, which also takes the bolts and clamps the bushing tightly to its ground seat. These stud bolts are usually made of "tobin bronze," a rust-proof material, possessing strength almost as great as that of steel. This arrangement permits ready removal of the bushing when necessary.

As the parts of the common pump valve illustrated in detail on Plate H must be often replaced during service of the pump, provision must be made for unscrewing the stem and substituting a new one. This must be done through the hand holes provided on the cylinder. The lower valve deck must be located so that the inner valves when unscrewed will not strike the clamp ring. As shown in Plate B the clearance is pretty small, almost too small, but as it affects only two valves, it will probably cause no inconvenience. No hand holes are necessary for the end chambers, as access to the valves is had by removing the outer heads. The upper deck may be placed at a height giving sufficient clearance to allow the upper nuts of the clamp ring to be unscrewed with a socket wrench from the end of the pump. These decks are subjected to a severe pounding from the pulsations of the pump, and should be amply strong; $1\frac{3}{4}$ inches is deemed thick enough for this case.

The middle transverse wall may be $1\frac{1}{2}$ inches thick and the middle longitudinal wall a little thinner, about $1\frac{1}{4}$ inches. With high pressures these walls, being flat surfaces and the valve decks likewise, are likely to fracture under the heavy pounding. To avoid making them excessively heavy they are often strongly ribbed, either on the inside or outside, usually the former.

The curving side walls are of better form to withstand pressure, and need not be as thick, 1 inch being sufficient. This can be decreased to $\frac{3}{4}$ inch in the suction passage below the deck, where little pressure exists.

The outer head is also considered strong enough at 1 inch thickness, on account of its curved shape. It requires $\frac{7}{8}$ -inch studs. Studs are preferred to tap bolts in this case, as in all other similar cases, on account of the frequent unscrewing of the nuts for purpose of removal. One or two unscrewings of a tap bolt in cast



iron will destroy the tightness of the thread, while the stud, being steel, stands the wear better.

The valve seats are taper screwed into the deck; they are sometimes forced in on a plain taper fit. They are located as closely as strength of the deck between the holes will permit. It is not well to place the edge of the valve closer than $\frac{1}{2}$ inch from the cylinder walls. The valve holes in the lower deck should be in line, or nearly so, with the holes in the upper deck, in order to allow the shank of the mill to pass through when milling the lower holes.

The suction opening is 7 inches in diameter, 12 $\frac{1}{2}$ -inch flange, 10 $\frac{1}{2}$ -inch bolt circle, $\frac{3}{4}$ -inch tapped holes.

By means of the hand hole at the end of the suction passage, any dirt which may have been brought in through the suction pipe may be removed.

The water cylinder cap, discharge ell and air chamber may be laid out from the detail Plate I, and the student must do this to see that the parts actually go together properly.

With the foregoing discussion the student should be able to produce Plate B, which is the preliminary step to the detail drawing of the water cylinder as shown on Plate J.

Plate J. Water Cylinder. The water cylinder is, perhaps, the most complicated detail that the student will meet in this set of plates. Fundamentally, it is simply a box with curved sides, divided by the several walls into five compartments, each of which communicates with the outside by a round nozzle or flange. If this basic idea be kept constantly in mind, the student will have no trouble in building up the detailed design.

This fundamental conception of a complicated piece is a very important idea, and should be developed carefully by the student. It is one of the great secrets of good design, both from an artistic and a commercial standpoint. We often see a machine which seems to begin anywhere and end nowhere; it appears to be a miscellaneous collection of bosses, lugs, ribs and flanges. There is no general prevailing shape to the structure, no harmony of the lines. This is because the designer, if he may be so called, did not have the fundamental notion of shape, to which all minor details should have been subordinated. He simply grouped

parts together, without considering the fundamental structure.

In this water cylinder the box is the basic part of the structure, and its lines must be first developed; they should be designed to convey a smooth, regular and consistent surface to the eye. Then the nozzles and flanges may be added as subordinate parts; they will merely interrupt, but not destroy, the prevailing outline of the box. The dotted lines in the cross-section views of Plate J show the general shape behind and beneath the nozzles.

The hand holes are the same as on Plate I, and the detail of the cover should specify the number required for both places.

Provision for draining the four chambers of the water cylinder is made by the $\frac{3}{8}$ -inch pipe tap holes at the lower deck, and the cap, likewise, by the single hole at the upper deck. Drip cocks are screwed into these holes.

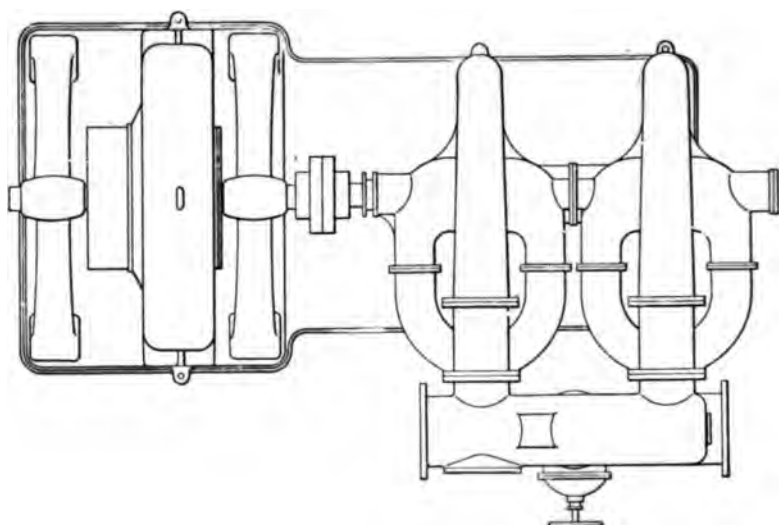
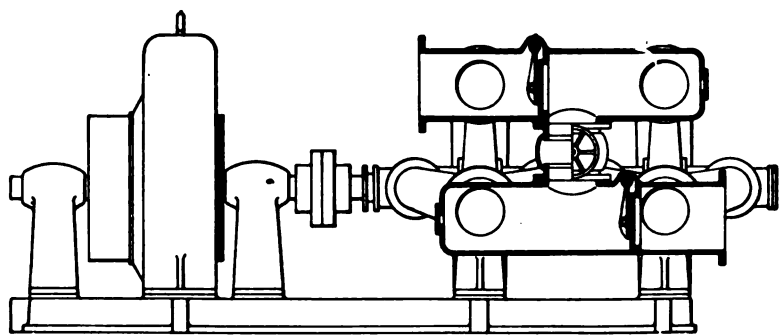
The holding-down bolts should not be less than 1 inch diameter; $1\frac{1}{4}$ inch would perhaps be better; and the holes in the foot should be drilled at least $\frac{1}{8}$ inch large.

Dimensions. It will be noticed that this plate has dimension lines, but no figures. This is because the cylinder is rather difficult to figure, and it is desired to guide the student in arrangement of the figures without lessening the benefit of his study of them. Special attention should be paid to this feature of the plate. Notice that although space for dimensions is restricted, a clear opening is always found for the figures; and when one view seems to offer no space for a figure, another view gives the desired opportunity.

No finish marks or titles are shown on this plate, these being left entirely to the student for insertion.

Molding. The centers of the curves for the sides being on the main horizontal axis of the nozzles, the cylinder, if molded to be cast vertically as shown, will draw readily both ways from this line. The exceptions to this easy draw are the foot, suction nozzle and flange, and hand-hole boss. On account of the inside of the cylinder being cored, these pieces if made loose on the pattern have ample space to be "pulled in" after the main pattern is withdrawn.

The suction passage below the deck communicates with the main core through the valve holes, hence it may be supported



SERIES MULTIPLE CENTRIFUGAL PUMP ELEVATION AND PLAN VIEWS.
Alberger Condenser Co.

from the main core. This involves some difficulty, however. If a three-part flask be used, and another parting established at the center of the suction flange, in addition to the previous one, the problem becomes much simplified.

It is desirable to make the four chambers of the cylinder alike in general proportions. It is then possible to make a single core-box, and by the use of loose pieces change the length of the nozzle cores and transpose from right to left, thus saving labor on the pattern. This, however, multiplies the loose pieces on the pattern. The many pieces are likely to become lost and make frequent repair necessary. Hence it is not always wise to use a single core box too much, and good judgment is required to fix the limit.

Machining. Special double horizontal boring machines are now in common use for such cases as this water cylinder. The centers are made adjustable, so that within limits any distance between piston-rod centers can be met. The advantages of double boring are, of course, most obvious for a considerable number of duplicate cylinders.

It will be noticed that the face of the suction flange is carried out flush with the cylinder head face. This affords opportunity for finishing all the end surfaces at a single setting of the tool, whether the work be done on the rotary or reciprocating planer. This same point might have been observed on the small hand-hole boss at the other end of the cylinder, but the advantage gained did not seem to warrant extending the "reach" through the hand hole.

Plate I. Water Cylinder, Cap and Air Chamber. For a water cylinder cap of this size, the most difficult problem is to find room for the hand-hole bosses. A hand hole 4 inches $\times$ 6 inches is about as small as can be used, and this calls for a flange at least 7 inches $\times$ 9 inches. These are the proportions shown on the plate, and since the boss overhangs the bolts in the main-cap flange, it must be cut away underneath to clear the nuts. If three stud bolts are used on each side, this overhang also requires that the nut be "fed on"; that is, screwed on little by little as the end of the stud protrudes above the flange when the cap is being lowered into place. This is an awkward process, but is sometimes necessary.

The discharge ell should have an easy bend; usually the radius is somewhat more than the outside diameter of the pipe, in this case 50 per cent greater. It is customary on this piece to provide an opening for the attachment of a relief valve as shown, 1½-inch pipe tap. This valve can be set to open at a desired pressure, so that the water end may be relieved in case of accidental excessive pressure.

The air chamber provides an air cushion for the water to make the delivery more constant, and take the shock which would otherwise come with hammer-like force and full intensity upon the cylinder. Being placed at the highest point of the water end, air will naturally tend to collect in the air chamber and keep it charged. In some cases, however, a special charging device is necessary.

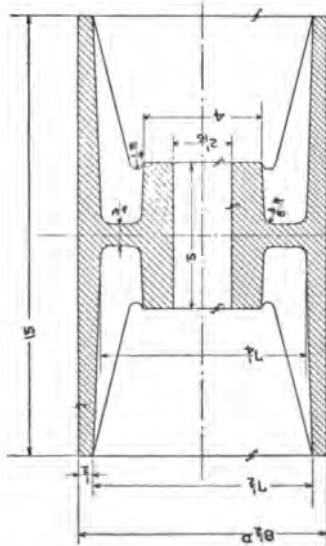
Molding and Machining. The hand holes being at an angle will not "draw." Hence cores must be set for these openings at least, and it may be desirable to core out the whole inside of the cap for the sake of keeping the pattern in good shape by making it solid. Otherwise it is easy to let it leave its own core.

The overhang of the hand-hole bosses requires loose pieces for the overhanging part. They are "pulled" in after the pattern is drawn.

The molding and machining which are further required on details of Plate I are simple, and require no special discussion.

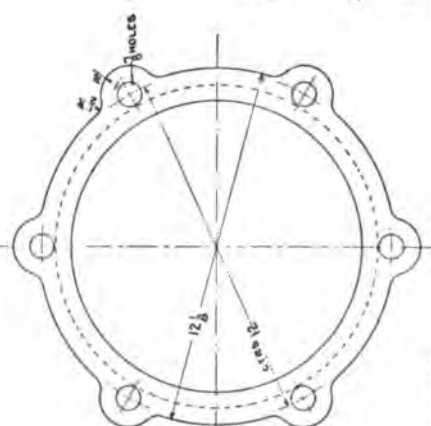
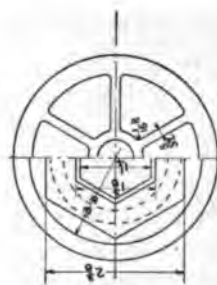
Plate H. Plunger and Valve Details. This plate is noticeable for illustrating a method of drawing details not used elsewhere in this set of plates. On the other plates each piece is separately detailed. On Plate H the details of the valve, cover, seat, stem and spring are shown assembled, and dimensioned without separation. This is an allowable method when clearness is not sacrificed, but it is usually found desirable only with simple construction. It concentrates parts on the drawing, and probably saves some time, besides showing the workman just how the parts go together. The only test which the student need to apply in this, as in any method of detailing, is the test for absolute clearness.

It is believed in the case of the valve as shown that the details are completely illustrated without sacrificing clearness. Special care in putting in dimensions is of necessity required.

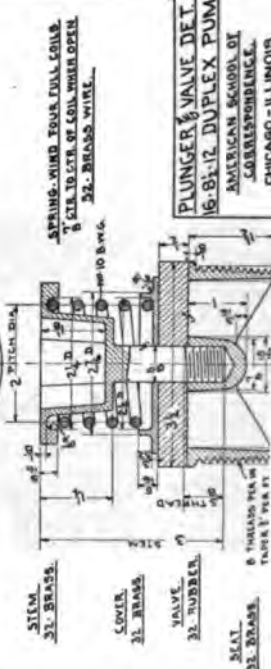
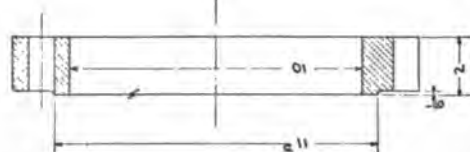


PLUNGER BUSHING.
TWO - BRASS.

PLUNGER.
TWO. C. I.



CLAMP RING
TWO-CL



PLUNGER VALVE DET.
16-8 1/2-12 DUPLEX PUMP.

AMERICAN SCHOOL OF
CORRESPONDENCE
CHICAGO - ILLINOIS

The valve stem can be unscrewed either with a socket wrench on the inside or an ordinary fork wrench on the outside.

The seat, after being screwed to position in the deck, is often faced off, to true up any distortion caused by screwing in.

The valve itself, of rubber, can be bought of any desired grade of hardness. The specification for any given set of valves depend upon the quality of the water, the pressure and the general service of the pump.

Molding and Machining. By reason of the simple nature of the parts on this plate, the molding and machining is left entirely to the original consideration of the student.

Plate M. Foundation. Pumps are often set directly upon a foundation of brick, but it makes a better job to bed stones, with surfaces dressed plane and true, into the main foundation, and rest the pump feet upon these stones. The simplest form of holding down bolts are shown on Plate M, a plain hook at the lower end, pulling up against a flat cast-iron plate, to distribute the pressure into the brickwork. These plates are of course bedded, and the bolts set as the foundation is built up. As the subsequent courses are laid some little space is left around the bolts, which may be afterwards filled with cement, thus making the bolts rigid with the foundation.

The water end of the foundation has no batter, because the suction pipe often drops vertically down from the end of the pump, and clearance is therefore necessary.

The floor line is placed 4 inches above the brickwork, to allow for the usual 1-inch top floor and 2-inch plank beneath, and still have a space left for shims to level the floor.

Plate N. General Drawing. This is an example of a plain, everyday shop drawing, to show the relation of parts and the extreme space occupied by the pump. A great deal of time can be needlessly wasted in producing a drawing of this character, by trying to make too faithful a picture. For example: If all the bolt heads were put in, it is safe to say that several hours' extra time would be required for this one item alone. But the drawing would be no better for shop use. Hence all bolt heads and nuts have been left out, except when necessary to show clearance.

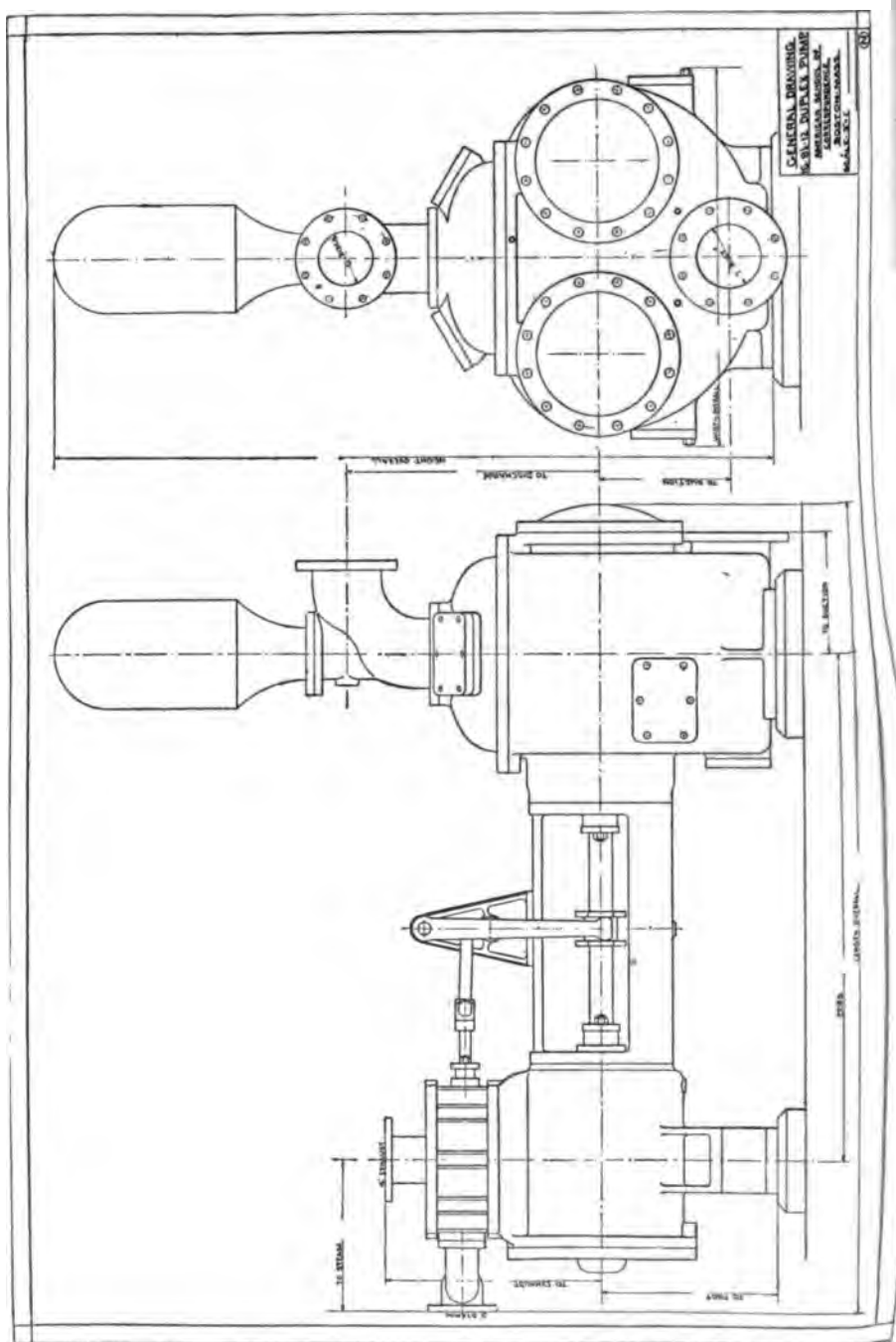
Shade lines have been put on for no special reason except

Architectural drawings of a foundation for a two-story building. The drawings include a plan view, a section view, and a detail view of the foundation wall.

Plan View: Shows a rectangular foundation with overall dimensions of 28'-0" by 11'-0". It includes a central line of water end and a central line of beam end. The foundation is labeled with dimensions and notes such as "BRICK LIND IN CEMENT BEDDED ON HARD PAN" and "FOUNDAION PLATE".

Section View: Shows the foundation wall with a 3'-4" stone base and a 1'-0" brickwork section. The wall is labeled with dimensions and notes such as "BRICK LIND IN CEMENT BEDDED ON HARD PAN" and "FOUNDAION PLATE".

Detail View: Shows the foundation wall with a 3'-4" stone base and a 1'-0" brickwork section. The wall is labeled with dimensions and notes such as "BRICK LIND IN CEMENT BEDDED ON HARD PAN" and "FOUNDAION PLATE".



that if they are desirable on any drawing they are especially desirable on a general drawing, where one part overlaps another, as they make it easier to pick out and separate one surface from another. Some lines are shaded in this drawing which are not strictly sharp edges. It is held, however, that the rounding of a corner ought not to destroy its character as an edge casting a shadow, and such lines are treated accordingly.

An assembled or general drawing of this character should be laid out strictly from the dimensions shown by the details. It thus serves a valuable purpose in checking up figures, and showing whether or not the parts will go together. The method or character of the work in no respect differs from that suggested for the detail drawings.

If a scale of 3 inches = 1 foot be used, the size of sheet must be 24 inches $\times$ 36 inches. The student, however, will perhaps find it easier to use a scale of $1\frac{1}{2}$ inches = 1 foot, in which case the ordinary size, 18 inches $\times$ 24 inches, will suffice. For such a small scale it will be found undesirable to attempt to put in any very small fillets and corners, although those that can be readily handled by the ordinary bow pen ought not to be omitted. As a matter of fact, the expert draftsman either leaves the corners sharp, as suggested, or puts in the smallest curves freehand.

Order Sheets. Any set of drawings is incomplete unless in connection with it a statement is made in tabular form of the complete make-up of the machine. An infinite variety of ways exists for making the specifications. Sometimes the tabulated data are placed on the general drawing. Most often, however, printed blanks are provided, usually of bond paper, arranged with special reference to the individual shop system and methods of handling work; these blanks are filled in by the draftsman, indexed and filed as a part of the set of drawings. They can be blue printed for use in the shops the same as a drawing. From these sheets stock is ordered, checked off, and watched in its process of manufacture.

Order sheets are indispensable in any well-ordered shop. Hence they are illustrated on pages 59, 60, 61 and 62 as the final step in the set of pump drawings. They are made as simple as possible, and are not intended to fit any special shop system. As

previously stated, the exact form and method of classification can be determined only when the shop conditions are known.

The student, having carefully followed through the preceding pages, must not think that he is master of pump construction, for even the type illustrated has been but touched upon. The object of the detailed discussion is to get the student in close touch with the spirit of construction, to make his drawings real serious work. It is hoped that the student will work just as though a machine were to be built from his drawings, and built to sell at a profit. Only in this way can advanced work in mechanical drawing be of benefit to him, for after becoming expert in the use of the instruments, no other advance is possible except advance in *thought*.

DATE. MAY 20, 1902.		AMERICAN SCHOOL OF CORRESPONDENCE AT ARMOUR INSTITUTE OF TECHNOLOGY CHICAGO, ILL.		TYPE. INSIDE PLUNGER.	
LIST OF CASTINGS					
FOR 16-81-12 DUPLEX PUMP.					
No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
2	Steam Cylinder	G		C. I.	R. & L.
2	Steam Cylinder Head	G		C. I.	
2	Steam Chest	F		C. I.	
2	Steam Chest Cover	F		C. I.	
2	Slide Valve	F		C. I.	
1	Steam Pipe	F		C. I.	
1	Exhaust Tee	F		C. I.	
2	Valve Steam Gland	F		C. I.	
2	Piston	E		C. I.	
8	Piston Pipe Plug, 1½"	E		C. I.	
4	Piston Packing Ring	E		C. I.	
2	Spool	E		C. I.	
1	Steam Cylinder Cricket	L		C. I.	
2	Steam Cylinder Stuffing Box	L		C. I.	
2	Water Cylinder Stuffing Box	L		C. I.	
4	Piston Rod Gland	L		C. I.	
1	Valve Lever Bracket	L		C. I.	
2	Yoke	L		C. I.	R. & L.
1	Short Rocker Arm	K		C. I.	
1	Long Rocker Arm	K		C. I.	
2	Valve Stem Link	K		C. I.	
1	Water Cylinder	J		C. I.	
2	Water Cylinder Head	J		C. I.	
3	Hand Hole Cover	J		C. I.	
1	Water Cylinder Cap	I		C. I.	
1	Air Chamber	I		C. I.	
1	Discharge Ell	I		C. I.	
2	Plunger	H		C. I.	
2	Plunger Bushing	H		Brass	
2	Clamp Ring	H		C. I.	
32	Valve Stem	H		Brass	
32	Valve Cover	H		Brass	
32	Valve Seat	H		Brass	
6	Foundation Plate	M		C. I.	

DATE. MAY 20, 1902.	AMERICAN SCHOOL OF CORRESPONDENCE AT ARMOUR INSTITUTE OF TECHNOLOGY CHICAGO, ILL.	TYPE. INSIDE PLUNGER.			
LIST OF STEEL AND MISCELLANEOUS PARTS					
FOR					
16-81-12 DUPLEX PUMP.					
No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
2	Valve Steam Head	E		St.	Drop Forging.
2	Piston Rod	E		C. R. S.	
2	Valve Stem	E		St.	
1	Long P. R. Lever	K		St.	Forging
1	Short P. R. Lever	K		St.	Forging
1	Upper Rocker Shaft	K		St.	
1	Lower Rocker Shaft	K		St.	
2	Rocker Arm Pin	K		St.	
2	Link Pin	K		St.	
1	Long P. R. Lever Key	K		St.	Drop Forging
1	Short P. R. Lever Key	K		St.	Drop Forging
2	Rocker Arm Key	K		St.	Drop Forging
32	Valve Spring	H		Brass wire	Spring Temper
32	Valve	H		Rubber	Medium

DATE.
MAY 20, 1902.

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

TYPE.
INSIDE PLUNGER.

LIST OF BOLTS, NUTS AND PINS

FOR

16-84-12 DUPLEX PUMP.

No. wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
24	Cylinder Head Stud $\frac{7}{8} \times 3\frac{1}{4}$	G		St.	
20	Steam Chest Stud $\frac{3}{4} \times 8\frac{3}{4}$	G		St.	
4	Valve Stem Gland Stud $\frac{5}{8} \times 4\frac{3}{4}$	F		St.	
8	Piston Rod Gland Stud $\frac{3}{4} \times 4$	L		St.	
24	Water Cylinder Head Stud $\frac{7}{8} \times 3\frac{1}{4}$	J		St.	
12	Clamp Ring Stud $\frac{3}{4} \times 4\frac{1}{4}$	J		Tobin bz.	
24	Water Cylinder Cap Stud $1 \times 3\frac{1}{4}$	J		St.	
18	Hand Hole Cover Stud $\frac{5}{8} \times 2\frac{1}{2}$	J		St.	
12	Hand Hole Cover Stud $\frac{5}{8} \times 2\frac{1}{2}$	I		St.	
8	Exhaust Tee Tap Bolt $\frac{5}{8} \times 1\frac{1}{2}$	G		St.	
16	Yoke Tap Bolt $\frac{3}{4} \times 2$	G		St.	
8	Steam Cyl. Stf. Box Tap Bolt $\frac{3}{4} \times 1\frac{1}{2}$	G		St.	
8	Steam Pipe Tap Bolt $\frac{5}{8} \times 1\frac{1}{4}$	F		St.	
4	Valve Lever Bracket Tap Bolt $\frac{5}{8} \times 1\frac{1}{2}$	F		St.	
4	Steam Cyl. Cricket Tap Bolt $1 \times 2\frac{1}{4}$	F		St.	
16	Yoke Tap Bolt $\frac{3}{4} \times 2$	J		St.	
8	Water Cyl. Stf. Box Tap Bolt $\frac{3}{4} \times 1\frac{1}{4}$	J		St.	
8	Discharge Ell Tap Bolt $\frac{3}{4} \times 2$	I		St.	
4	Air Chamber Tap Bolt $\frac{3}{4} \times 2$	I		St.	
2	Hook Bolt (special) $1 \times 3' - 11"$	M		St.	
4	Hook Bolt (special) $1\frac{1}{4} \times 3' - 11"$	M		St.	
1	Eye Bolt Standard $1"$	I		St.	
34	Standard Nut $\frac{5}{8}$			St.	
44	Standard Nut $\frac{3}{4}$			St.	
36	Standard Nut $\frac{7}{8}$			St.	
26	Standard Nut 1			St.	
4	Standard Nut $1\frac{1}{4}$			St.	
4	Standard Nut 2			St.	
8	Special Valve Stem Nut 1			St.	$\frac{1}{4}$ Thick
4	Piston Rod Split Pin $\frac{1}{4} \times 2$	E		St.	
2	Spool Taper Pin No. 10 Morse Taper	E		St.	4" long
4	Valve Bracket Dowel Pin $\frac{1}{4} \times 2$	L		St.	

DATE, MAY 20, 1902.		AMERICAN SCHOOL OF CORRESPONDENCE AT ARMOUR INSTITUTE OF TECHNOLOGY CHICAGO, ILL.		TYPE. INSIDE PLUNGER.	
LIST OF SPECIAL FITTINGS, WRENCHES, ETC.					
FOR 16-84-12 DUPLEX PUMP.					
No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
4	Drip Cock $\frac{1}{2}$ "	G			
1	Drip Cock $\frac{1}{4}$ "	F			
2	Drip Cock $\frac{1}{4}$ "	L			
4	Oil Cup $\frac{1}{4}$ "	L			
5	Drip Cock $\frac{3}{8}$ "	J			
1	Relief Valve $1\frac{1}{4}$ "	I			175 lbs. pressure
1	Standard Fork Wrench 8"				
1	Standard Fork Wrench $\frac{3}{4}$ "				
1	Standard Fork Wrench $\frac{7}{8}$ "				
1	Standard Fork Wrench 1"				
1	Socket Wrench $\frac{3}{4}$ "				12" handle
1	Valve Stem Fork Wrench				
1	Valve Stem Socket Wrench				

PLATES.

The plates of Part VI (A to N, inclusive,) are so arranged and described that the complete set may be made by the student. In case of insufficient time, the following short examination is prescribed. The student in any case should read carefully all the text, and follow the discussion of all the plates, whether or not actually produced by him.

PLATE XXV.

Reproduce Plate E (page 32), putting on shade lines. Size of plate to be 18 inches $\times$ 24 inches, trimmed, with border $\frac{1}{2}$ inch from edge; size within border line, 17 inches $\times$ 23 inches.

PLATE XXVI.

Make steam end layout, Plate A (page 10). This is to be done accurately *in pencil*. Size same as Plate XXV.

PLATE XXVII.

Make drawing of steam cylinder, Plate G (page 18), complete, with finish marks and dimensions. Do not put on shade lines.

PLATE XXVIII.

Draw valve motion layout, Plate C (page 36). This plate also is to be done accurately *in pencil*.

PLATE XXIX.

Make rough freehand sketches in pencil of parts on Plate I (page 42), putting on finish marks and dimensions. Use a medium pencil, and make sheet of regular size (18 inches $\times$ 24 inches). Arrangement to be similar to Plate L. Do not try to make the sketches to scale, but make them sufficiently complete so that detail drawings can be made from them.

PLATE XXX.

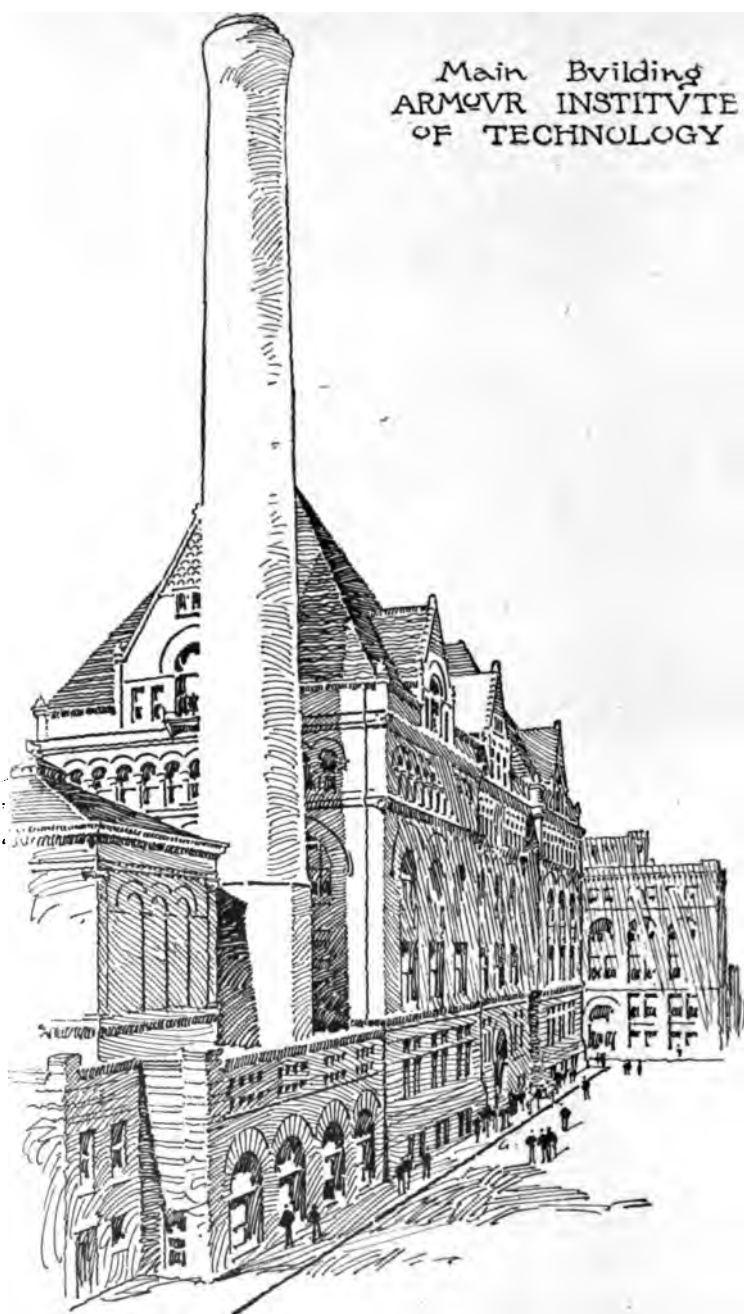
Make a tracing on tracing cloth of Plate E (page 32).

PLATE XXXI.

Make general drawing Plate N. Use scale of $1\frac{1}{2}" = 1'$, or $3" = 1'$.

PLATE XXXII (Optional).

Make drawing of water cylinder, Plate J (page 48).



A STUDY IN PEN AND INK RENDERING.

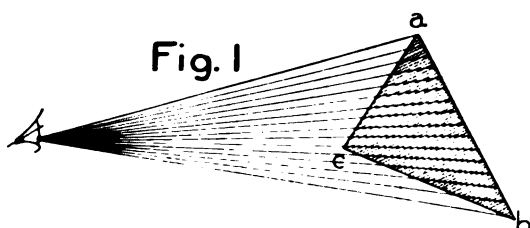
(For a different treatment of the same building, see page 440.)

PERSPECTIVE DRAWING.

DEFINITIONS AND GENERAL THEORY.

1. WHEN any object in space is being viewed, rays of light are reflected from all points of its visible surface, and enter the eye of the observer. These rays of light are called **visual rays**. They strike upon the sensitive membrane, called the retina, of the eye, and form an image. It is from this image that the observer receives his impression of the appearance of the object at which he is looking.

2. In Fig. 1, let the triangular card *abc* represent any object in space. The image of it on the retina of the observer's eye will be formed by the visual rays reflected from its surface. These rays form a pyramid or cone which has the observer's eye for its apex, and the object in space for its base.

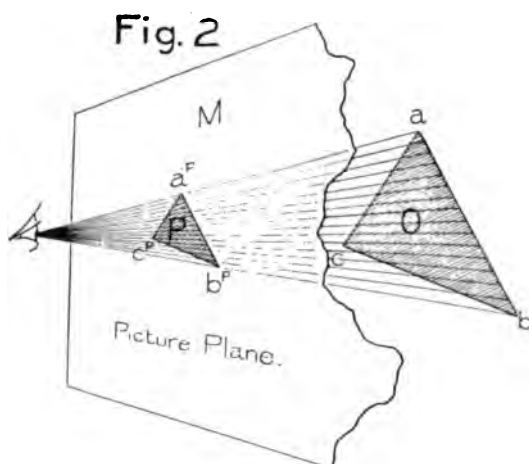


3. If a transparent plane *M*, Fig. 2, be placed in such a position that it will intersect the cone of visual rays as shown, the intersection will be a **projection** of the object upon the plane *M*. It will be noticed that the projecting lines, or **projectors**, instead of being perpendicular to the plane, as is the case in orthographic projection,* are the visual rays which all converge to a single point coincident with the observer's eye.

* In orthographic projection an object is represented upon two planes at right angles to each other, by lines drawn perpendicular to these planes from all points on the edges or contour of the object. Such perpendicular lines intersecting the planes give figures which are called **projections (orthographic)** of the object.

4. Every point or line in the projection on the plane M will appear to the observer exactly to cover the corresponding point or line in the object. Thus the observer sees the point a^p in the projection, apparently just coincident with the point a in the object. This must evidently be so, for both the points a^p and a lie on the same visual ray. In the same way the line $a^p b^p$ in the projection must appear to the observer to exactly cover the line ab in the object; and the projection, as a whole, must present to him exactly the same appearance as the object in space.

5. If the projection is supposed to be permanently fixed



upon the plane, the object in space may be removed without affecting the image on the retina of the observer's eye, since the visual rays which were originally reflected from the surface of the object are now reflected from the projection on the plane M . In other words, this projection may be

used as a substitute for the object in space, and when placed in proper relation to the eye of the observer, will convey to him an impression exactly similar to that which would be produced were he looking at the real object.

6. A projection such as that just described is known as a **perspective projection** of the object which it represents. The plane on which the perspective projection is made is called the **Picture Plane**. The position of the observer's eye is called the **Station Point**, or **Point of Sight**.

7. It will be seen that the perspective projection of any point in the object, is where the visual ray, through that point, pierces the picture plane.

8. A perspective projection may be defined as the represen-

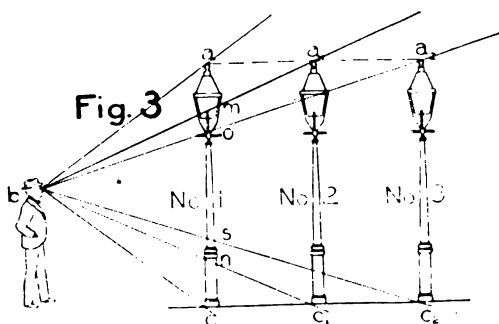
tation, upon a plane surface, of the *appearance* of objects as seen from some given point of view.

9. Before beginning the study of the construction of the perspective projection, some consideration should be given to phenomena of perspective. One of the most important of these phenomena, and one which is the keynote to the whole science of perspective, has been noticed by everyone. It is the *apparent* diminution in the size of an object as the distance between the object and the eye increases. A railroad train moving over a long, straight track, furnishes a familiar example of this. As the train moves farther and farther away, its dimensions apparently become smaller and smaller, the details grow more and more indistinct, until the whole train appears like a black line crawling over the ground. It will be noticed also, that the speed of the train seems to diminish as it moves away, for the equal distances over which it will travel in a given time, seem less and less as they are taken farther and farther from the eye.

10. In the same way, if several objects having the same dimensions are situated at different distances from the eye, the nearest one appears to

be the largest, and the others appear to be smaller and smaller as they are farther and farther away. Take, for illustration, a long, straight row of street-lamps. As one looks along the row, each succeeding lamp is ap-

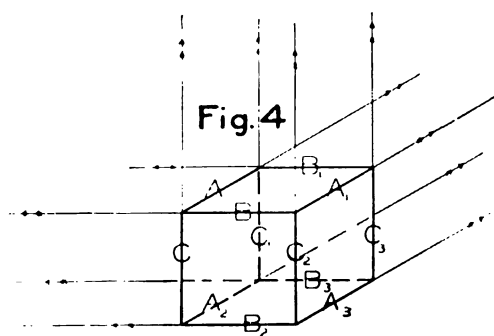
parently shorter and smaller than the one before. The reason for this can easily be explained. In estimating the size of any object, one most naturally compares it with some other object as a standard or unit. Now, as the observer compares the lamp-posts, one with another, the result will be something as follows (see Fig. 3). If he is looking at the top of No. 1, along the line *ba*, the top of No. 2 is invisible. It is apparently below the top of No. 1, for, in order to see No. 2, he has to lower his eye until he is looking in



the direction ba_1 . He now sees the top of No. 2, but the top of No. 1 seems some distance above, and he naturally concludes that No. 2 appears shorter than No. 1. As the observer looks at the top of No. 2, No. 3 is still invisible, and, in order to see it, he has to lower his eye still farther. Comparing the bottoms of the posts, he finds the same apparent diminution in size as the distance of the posts from his eye increases. The length of the second post appears only equal to the distance mn as measured on the first post, while the length of the third post appears only equal to the distance os as measured on post No. 1.

11. In the same way that the lamp-posts appear to diminish in size as they recede from the eye, the parallel lines (a, a_1, a_2 , etc., and c, c_1, c_2 , etc.) which run along the tops and bottoms of the posts appear to converge as they recede, for the distance between these lines seems less and less as it is taken farther and farther away. At infinity the distance between the lines becomes zero, and the lines appear to meet in a single point. This point is called the **vanishing point** of the lines.

12. If any object, as, for illustration, a cube, is studied, it

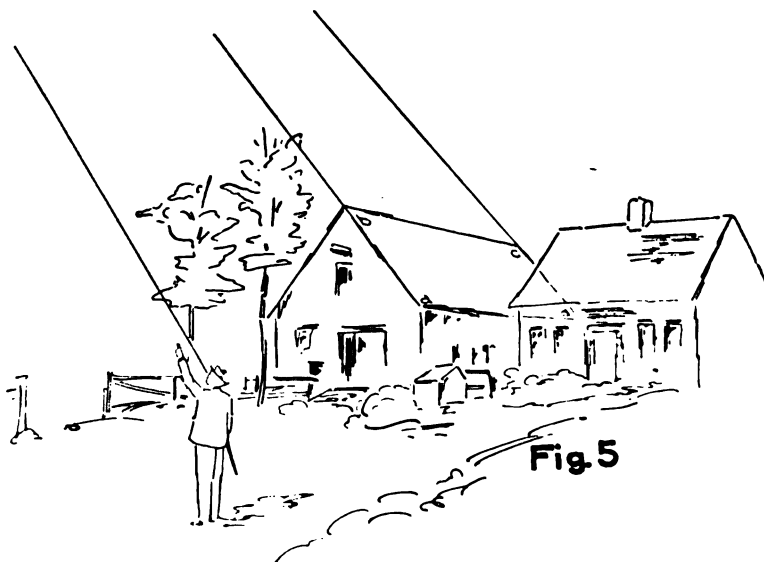


into groups according to their different directions; all lines having the same direction forming one group, and apparently converging to a common vanishing point. Each group of parallel lines is called a **system**, and each line an **element** of the sys-

tem. For example, in Fig. 4, A, A_1, A_2 , and A_3 belong to one group or system; B, B_1, B_2 , and B_3 , to another; and C, C_1, C_2 , and C_3 , to a third. Each system has its own vanishing point, towards which all the elements of that system appear to converge. This phenomenon is well illustrated in the parallel lines of a railroad track, or by the horizontal lines which form the courses of a stone wall.

13. As all lines which belong to the same system appear to meet at the vanishing point of their system, it follows that *if the eye is placed so as to look directly along any line of a system, that line will be seen endwise, and appear as a point exactly covering the vanishing point of the system to which it belongs.*

If, for illustration, the eye glances directly along one of the horizontal lines formed by the courses of a stone wall, this line will be seen as a point, and all the other horizontal lines in the wall will apparently converge towards the point. In other words, the line along which the eye is looking appears to cover the vanishing point of the system to which it belongs. Thus, the vanish-



ing point of any system of lines must lie on that element of the system which enters the observer's eye, and must be at an infinite distance from the observer. Therefore, to find the vanishing point of any system of lines, imagine one of its elements to enter the observer's eye. This element is called the **visual element** of the system, and may often be a purely imaginary line indicating simply the direction in which the vanishing point lies. The vanishing point will always be found on this visual element and at an infinite distance from the observer.

14. To further illustrate this point, suppose an observer to be viewing the objects in space represented in Fig. 5. He desires

to find the vanishing point for the system of lines parallel to the oblique line *ab* which forms one edge of the roof plane *abcd*. There are two lines in the roof that belong to this system, namely: *ab* and *dc*. If he imagines an element of the system to enter his eye, and looks directly along this element, he will be looking in a direction exactly parallel to the line *ab*, and he will be looking directly at the vanishing point of the system (§ 13). This visual element along which he is looking is a purely imaginary line parallel to *ab* and *dc*. All lines in the object belonging to this system will appear to converge towards a point situated on the line along which he is looking, and at an infinite distance from him.

This phenomenon is of great importance, and is the foundation of most of the operations in making a perspective drawing.

15. The word "vanish" as used in perspective always implies a recession. Thus, a line that vanishes upward, slopes upward as it *recedes* from the observer; a line that vanishes to the right, slopes to the right as it *recedes* from the observer.

16. It follows from paragraphs 13 and 14 that any system of lines that vanishes upward, will have its vanishing point above the observer's eye. Similarly, any system vanishing downward, will have its vanishing point below the observer's eye; any system vanishing to the right, will have its vanishing point to the right of the observer's eye; and any system vanishing to the left, will have its vanishing point to the left of the observer's eye. Any system of horizontal lines will have its vanishing point on a level with the observer's eye, and a system of vertical lines will have its vanishing point vertically in line with the observer's eye.

17. All planes that are parallel to one another are said to belong to the same system, each plane being called an element of the system.

All the planes of one system appear to approach one another as they recede from the eye, and to meet at infinity in a single straight line called the **vanishing trace** of the system. Thus, the upper and lower faces of a cube seen in space, will appear to converge toward a straight line at infinity.

18. If the eye is so placed as to look directly along one of

the planes of a system, that plane will be seen edgewise, and will appear as a single straight line exactly covering the vanishing trace of the system to which it belongs. The plane of any system that passes through the observer's eye is called the **visual plane** of that system.

19. From § 18, it follows that the vanishing trace of a system of planes that vanishes upward, will be found above the level of the eye, while the vanishing trace of a system of planes vanishing downward, will be found below the level of the eye. The vanishing trace of a system of vertical planes will be a vertical line; and of a system of horizontal planes, a horizontal line, exactly on a level with the observer's eye.

20. The vanishing trace of the system of horizontal planes is called the **horizon**.

The visual plane of the horizontal system is called the **plane of the horizon**. The plane of the horizon is a most important one in the construction of a perspective projection.

21. From the foregoing discussion the truth of the following statements will be evident. They may be called the Five Axioms of Perspective.

(a) *All the lines of one system appear to converge and to meet at an infinite distance from the observer's eye, in a single point called the vanishing point of the system.*

(b) *All the planes of one system appear to converge as they recede from the eye, and to meet at an infinite distance from the observer, in a single straight line called the vanishing trace of the system.*

(c) *Any line lying in a plane will have its vanishing point somewhere in the vanishing trace of the plane in which it lies.*

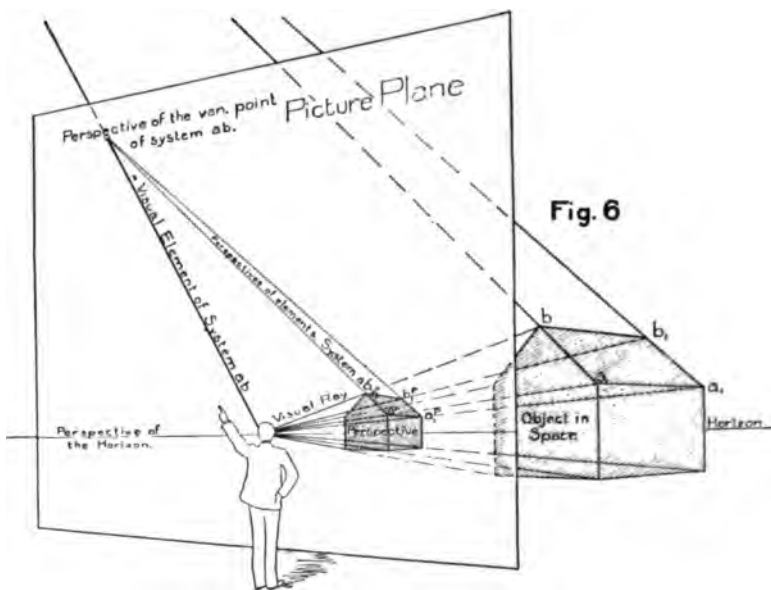
(d) *The vanishing trace of any plane must pass through the vanishing points of all lines that lie in it. Thus, since the vanishing trace of a plane is a straight line (§ 18), the vanishing points of any two lines lying in a plane will determine the vanishing trace of the system to which the plane belongs.*

(e) *As the intersection of two planes is a line lying in both, the vanishing point of this intersection must lie in the vanishing traces of both planes, and hence, at the point where the vanishing traces of the two planes cross. In other words, the vanishing point*

of the intersection of two planes must lie at the intersection of the vanishing traces of the two planes.

22. The five axioms in the last paragraph are the statements of purely imaginary conditions which appear to exist, but in reality do not. Thus, parallel lines appear to converge and to meet at a point at infinity, but in reality they are exactly the same distance apart throughout their length. Parallel planes appear to converge as they recede, but this is a purely apparent condition, and not a reality; the real distance between the planes does not change.

23. The perspective projection represents by real conditions the purely imaginary conditions that appear to exist in space.



Thus, the apparent convergence of lines in space is represented by a real convergence in the perspective projection. Again, the vanishing point of a system of lines is a purely imaginary point which does not exist. But this imaginary point is represented in perspective projection by a real point on the picture plane.

From § 14, the vanishing point of any system of lines lies upon the visual element of that system. This visual element may be considered to be the visual ray which projects the vanish-

ing point to the observer's eye. Hence, from § 7, the intersection of this visual element with the picture plane will be the perspective of the vanishing point of the system to which it belongs. This is illustrated in Fig. 6. The object in space is shown on the right of the figure. If the observer wishes to find the vanishing point of the oblique line ab in the object in space, he imagines a line parallel to ab to enter his eye, and looks along this line (§ 13). Where this line along which he is looking pierces the picture plane, will be the perspective of the vanishing point. Furthermore, the perspective of the line ab has been found by drawing the visual rays from a and b respectively, and finding where these rays pierce the picture plane (§ 7). These points are respectively, a^p and b^p , and the straight line drawn between a^p and b^p is the perspective of the line ab . The perspective of the line a_1b_1 which is parallel to ab , has been found in a similar way, and it will be noticed that its perspective projection ($a_1^p b_1^p$) actually converges towards $a^p b^p$ in such a manner that if these two lines are produced they will actually meet at the perspective of the vanishing point of their system.

NOTE.— *It is evident that the perspective of a straight line will always be a straight line, the extreme points of which are the perspectives of the extremities of the given line.*

24. Thus, the five axioms of perspective may be applied to Perspective Projection as follows:—

(a) Parallel lines do converge and meet at the vanishing point of their system.

(b) Parallel planes do converge and meet at the vanishing trace of their system.

(c) The vanishing point of any line lying in a plane will be found in the vanishing trace of the plane.

Therefore, the vanishing points of all horizontal lines will be found in the horizon (§ 20).

(d) The vanishing trace of any plane will be determined by the vanishing points of any two lines that lie in it, and must contain the vanishing points of all lines that lie in it.

(e) The vanishing point of the intersection of two planes will be found at the intersections of the vanishing traces of the two planes.

To the five axioms of perspective projection already stated may be added the following three truths concerning the construction of the perspective projection :—

(f) The perspective of any point in space is where the visual ray through the point pierces that picture plane (§ 7).

(g) The perspective of the vanishing point of any system of lines is where the visual element of that system pierces the picture plane.

Rule for finding the perspective of the vanishing point of any system of lines :—Draw an element of the system through the observer's eye, and find where it pierces the picture plane.

(h) Any point, line, or surface which lies in the picture plane will be its own perspective, and show in its true size and shape.

25. Knowing how to find the perspective of any point, and how to find the vanishing point of any system of lines, any problem in perspective may be solved. Therefore, it may be said that the whole process of making a perspective projection reduces itself to the problem of finding where a line pierces a plane.

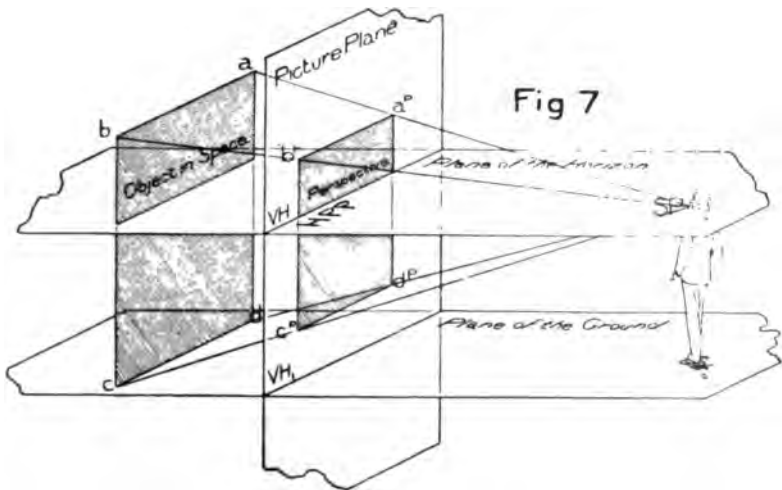
Before proceeding farther, the student should review the first twenty-five paragraphs by answering carefully the following questions :—

- (1) What does a perspective projection represent?
- (2) What is a visual ray?
- (3) How is a perspective projection formed?
- (4) How does a perspective projection differ from an orthographic projection?
- (5) What is the plane called on which the perspective projection is made?
- (6) What is meant by the term Station Point?
- (7) What is the most important phenomenon of perspective?
- (8) What is meant by a system of lines?
- (9) What is meant by a system of planes?
- (10) What is a visual element?
- (11) Define vanishing point.
- (12) Define vanishing trace.
- (13) Describe the position of the vanishing point of any system of lines.

- (14) Give the five axioms of perspective.
- (15) Do parallel lines in space really converge?
- (16) Do the perspective projections of parallel lines really converge?
- (17) Where will the perspective projections of parallel lines meet?
- (18) How is the perspective of any point found?
- (19) How is the perspective of the vanishing point of any system of lines found?
- (20) What will be the perspective of a straight line?
- (21) What is meant by the horizon?
- (22) What is meant by the plane of the horizon?

THE PLANES OF PROJECTION.

26. Two planes of projection at right angles to one another, one vertical and the other horizontal, are used in making a perspective. In Fig. 7 these two planes are shown in oblique pro-



jection. The vertical plane is the picture plane (§ 6 and Fig. 7) on which the perspective projection is made, and corresponds exactly to the vertical plane, or vertical coordinate used in orthographic projections.

27. The horizontal plane, or plane of the horizon (§ 20 and Fig. 7), *always passes through the assumed position of the observer's eye*, and corresponds exactly to the horizontal plane or horizontal coordinate used in orthographic projections.

28. All points, lines, surfaces, or solids in space, the perspective projections of which are to be found, are represented by their orthographic projections on these two planes, and their perspectives are determined from these projections.

29. Besides these two principal planes of projection, a third plane is used to represent the plane on which the object is supposed to rest (Fig. 7). This third plane is horizontal, and is called the plane of the ground. Its relation to the plane of the horizon determines the nature of the perspective projection. To illustrate: The observer's eye must *always* be in the plane of the horizon (§ 27), while the object, the perspective of which is to be made, is usually supposed to rest upon the plane of the ground. In most cases the plane of the ground will also be the plane on which the observer is supposed to stand, but this will not always be true. The observer may be standing at a much higher level than the plane on which the object rests, or he may be standing below that plane. It is evident, therefore, that if the plane of the ground is chosen far below the plane of the horizon, the observer's eye will be far above the object, and the resulting perspective projection will be a "bird's-eye view." If, on the other hand, the plane of the ground is chosen above the plane of the horizon, the observer's eye will be below the object, and the resulting perspective projection will show the object as though being viewed from below. This has sometimes been called a "worm's-eye view," or a "toad's-eye view."

Usually the plane of the ground is chosen so that the distance between it and the plane of the horizon is about equal (at the scale of the drawing) to the height of a man. This is the position indicated in Fig. 7, and the resulting perspective will show the object as though seen by a man standing on the plane on which the object rests.

30. The intersection of the *picture plane* and the *plane of the horizon* corresponds to the *ground line* used in the study of projections, in Mechanical Drawing. For more advanced work, how-

ever, there is some objection to this term. The intersection of the two coordinate planes has really no connection with the ground, and if the term "ground line" is used, it is apt to result in a confusion between the intersection of the two coordinate planes, and the intersection of the auxiliary plane of the ground, with the picture plane.

31. The intersection of the two coordinate planes is usually lettered VH on the picture plane, and HPP on the plane of the horizon. (See Fig. 7.) That is to say: When the vertical plane is being considered, VH represents the intersection of that plane with the plane of the horizon. It should also be considered as the *vertical projection of the plane of the horizon*. See Mechanical Drawing Part III, page 5, paragraph in italics. All points, lines, or surfaces lying in the plane of the horizon will have their *vertical projection* in VH.

32. On the other hand, when the horizontal plane is being considered, HPP represents the intersection of the two planes, and also the *horizontal projection of the picture plane*. All points, lines, or surfaces in the picture plane will have their *horizontal projections* in HPP. Thus, instead of considering the intersection of the two coordinate planes a single line, it should be considered the coincidence of two lines, i.e.: First, the vertical projection of the plane of the horizon; second, the horizontal projection of the picture plane.

33. The plane of the ground is always represented by its intersection with the picture plane (see VH_1 , Fig. 7). Its only use is to determine the relation between the plane of the horizon and the plane on which the object rests (§ 29). The true distance between these two planes is always shown by the distance between VH and VH_1 as drawn on the picture plane.

34. To find the perspective of a point determined by its vertical and horizontal projections.

Fig. 8 is an oblique projection showing the two coordinate planes at right angles to each other. The assumed position of the plane of the ground is indicated by its **vertical trace** (VH.).

NOTE. — The *vertical trace* of any plane is the intersection of that plane with the vertical coordinate. The *horizontal trace* of any plane is the intersection of that plane with the horizontal coordinate.

The assumed position of the station point is indicated by its two projections, SP^V and SP^H . Since the station point lies in the plane of the horizon (§ 27), it is evident that its true position must coincide with SP^H , and that (§ 31) its vertical projection must be found in VH , as indicated in the figure. Let the point a represent any point in space. The perspective of the point a will be at a^P , where a visual ray through the point a pierces the picture plane (§ 24). We may find a^P in the following manner, by using the orthographic projections of the point a , instead of the point itself. a^H represents the *horizontal projection*, and a^V represents the *vertical projection* of the point a . A line drawn from the *vertical projection* of the point a to the *vertical projection* of the station point, will represent the *vertical projection of the visual ray*, which passes through the point a . In Fig. 8 this vertical projection is represented by the line drawn on the picture plane from a^V to SP^V .

A line drawn from the *horizontal projection* of a to the *horizontal projection* of the station point will represent the *horizontal projection of the visual ray*, which passes through the point a . In Fig. 8, this horizontal projection is represented by the line drawn on the plane of the horizon from a^H to SP^H . Thus we have, drawn upon the planes of projection, the vertical and horizontal projections of the point a , and the vertical and horizontal projections of the visual ray passing between the point a and the station point.

35. We must now find the intersection of the visual ray with the picture plane. This intersection will be a point in the picture plane. It is evident that its vertical projection must coincide with the intersection itself, and that its horizontal projection must be in HPP (§ 32). But this intersection must also be on the visual ray through the point a , and consequently the horizontal projection of this intersection must be on the horizontal projection of the visual ray. Therefore, the horizontal projection of this intersection must be the point m^H , where the line between

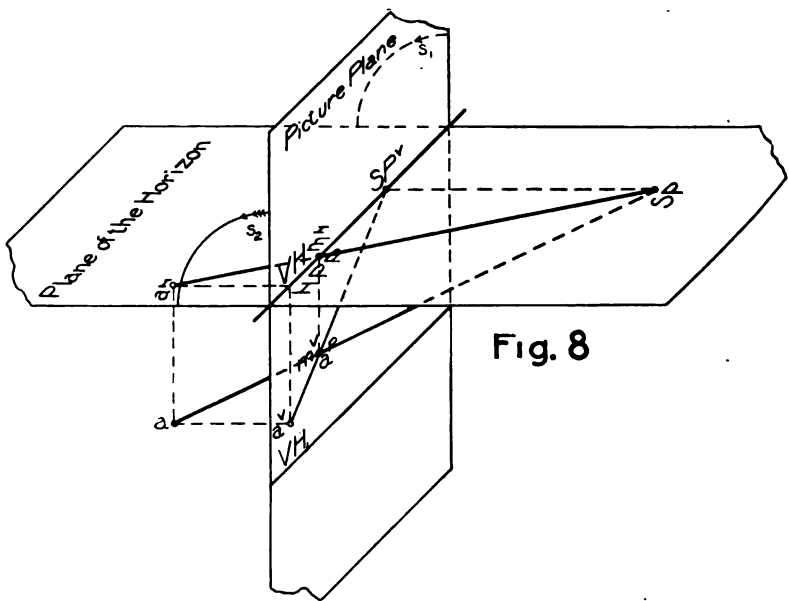


Fig. 8

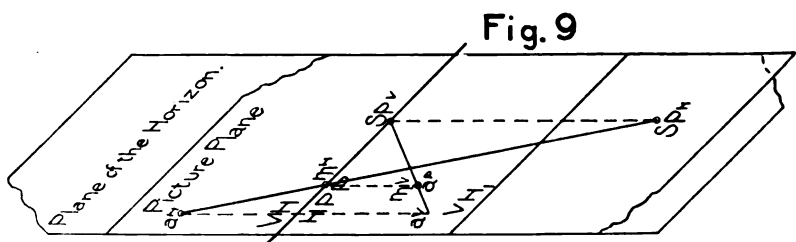


Fig. 9

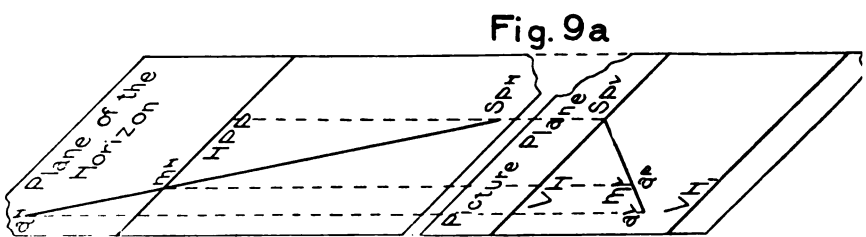


Fig. 9a

SP^H and a^H crosses HPP. The vertical projection of this intersection must be vertically in line with this point, and on the line drawn between SP^V and a^V , and hence at m^V . Since the vertical projection of the intersection coincides with the intersection itself, a^P (coincident with m^V) must be the perspective of the point a .

36. This is the method of finding the perspective of any point, having given the vertical and horizontal projections of the point and of the station point. The method may be stated briefly as follows:—

Draw through the horizontal projection of the point and the horizontal projection of the station point, a line representing the horizontal projection of the visual ray, which passes through the point. Through the intersection of this line with HPP, draw a vertical line. The perspective of the point will be found where this vertical line crosses the vertical projection of the visual ray, drawn through SP^V and a^V .

37. It would evidently be inconvenient to work upon two planes at right angles to one another, as shown in Fig. 8. To avoid this, and to make it possible to work upon a plane surface, the picture plane (or vertical coordinate) is supposed to be revolved about its intersection with the plane of the horizon, until the two coincide and form one surface. The direction of this revolution is indicated by the arrows s_1 and s_2 . After revolution, the two coordinate planes will coincide, and the vertical and horizontal projections overlap one another, as indicated in Fig. 9.

It will be noticed that the coincidence of the two planes in no way interferes with the method given in § 36, of finding the perspective (a^P) of the point a , from the vertical and horizontal projections of the point. Thus, the horizontal projection of the visual ray through the point will be seen, drawn from SP^H to a^H , and intersecting HPP in the point m^H . The vertical projection of the visual ray through the point will be seen passing from SP^V to a^V . And a^P is found upon the vertical projection of the visual ray, directly under m^H .

It will readily be understood that in a complicated problem, the overlapping of the vertical and horizontal projections

result in some confusion. It is, therefore, usually customary, after having revolved the two coordinate planes into the position shown in Fig. 9, to slide them apart in a direction *perpendicular to their line of intersection*, until the two planes occupy a position similar to that shown in Fig. 9a.

38. It will be remembered from the course on projections which the student is supposed to have taken, that *horizontal projections must always be compared with horizontal, and never with vertical projections*, and that in the same way, *vertical projections must always be compared with vertical, and never with horizontal projections*. It is evident that in sliding the planes apart, the relations between the projections on the vertical plane will not be disturbed, nor will the relations between the projections on the horizontal plane, and consequently it will make no difference how far apart the two coordinate planes are drawn, provided that horizontal and vertical projections of the same points are always kept in line. Thus, in Fig. 9a, it will be seen that in drawing the planes apart, a^V has been kept in line with a^H , m^V with m^H , SP^V with SP^H , etc.

39. It will be observed that in sliding the planes apart, their line of intersection has been separated into its two projections (§§ 31 and 32). HPP, being on the plane of the horizon or horizontal coordinate, is the *horizontal projection of the intersection* of the two planes, while VII, being on the picture plane or vertical coordinate, is the *vertical projection of the intersection* of the two planes. In the original position of the planes (Fig. 9) these two projections were coincident. The distance between HPP and VII always represents the distance through which the planes have been slid. This distance is immaterial, and will have *no effect* on the perspective drawing. VII₁ represents the vertical trace of the plane of the ground.

In this figure, as in the case of Fig. 9, the student should follow through the construction of the perspective of the point a , applying the method of § 36.

40. Fig. 10 shows the position of the two coordinate planes and of the plane of the ground, as they are usually represented on the drawing board in making a perspective drawing. It is essentially the same thing as Fig. 9a, except that the latter was

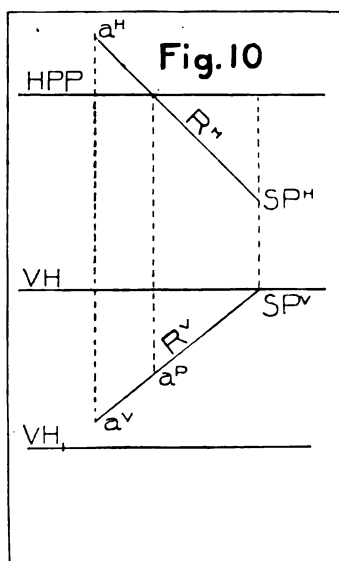
shown in oblique projection in order that its development from the original position of the planes (Fig. 8) might be followed more readily. The two coordinate planes are supposed to lie in the plane of the paper.

HPP represents the horizontal projection of the picture plane, and VH represents the vertical projection of the plane of the horizon.

As horizontal projections are never compared with vertical projections (§ 38), HPP may be drawn as far from, or as near, VH as desired, without in any way affecting the resulting perspective drawing. HPP and VH were coincident in Fig. 9, and the distance between them in Fig. 10 simply shows the distance that the two planes have been slid apart, as illustrated in Fig. 9a. As already stated, this distance is immaterial, and may be made whatever is most convenient, according to the nature of the problem.

If HPP should be placed nearer the top of the sheet, a^H and SP^H , both being horizontal projections, would follow it, the relation between these horizontal projections always being preserved.

On the other hand, SP^V , a^V , a^P , VH, and VH_1 , all being projections on the vertical plane, must preserve their relation with one another, and will in no way be affected if the group of projections on the horizontal coordinate is moved nearer or farther away. It must be borne in mind, however, that, in all cases, the vertical and horizontal projections of corresponding points must be kept vertically in line. Thus, a^H must always be vertically in line with a^V . The vertical distance between these two projections does not matter, provided the distance from a^H to HPP, or the distance from a^V to VH, is not changed. This point cannot be too strongly emphasized.



41. Suppose it is desired to determine from Fig. 10 how far the station point lies in front of the picture plane. This is a horizontal distance, and therefore will be shown by the distance between the horizontal projection of the station point and the horizontal projection of the picture plane, or, in other words, by the distance between SP^H and HPP .

42. The point a is a certain distance above or below the plane of the horizon. This is a *vertical distance*, and will be shown by the distance between the *vertical projection* of the point a and the *vertical projection* of the plane of the horizon; in other words, by the distance between a^V and VH . It will be seen that in Fig. 10 the point a lies below the plane of the horizon.

43. If it be desired to find how far in front or behind the picture plane the point a lies, this is a *horizontal distance*, and will be shown by the distance between the *horizontal projection* of the picture plane and *horizontal projection* of the point a , that is, by the distance between HPP and a^H . In Fig. 10 the point a lies behind the picture plane.

44. The distance between the plane of the ground and the plane of the horizon is a vertical distance, and will be shown by the distance between the vertical projection of the plane of the horizon and the vertical projection of the plane of the ground; i.e., the distance between VH and VH_1 . The distance between the observer's eye and the plane of the ground is also a vertical distance, and will be shown by the distance between SP^V and VH_1 ; but as SP^V must always be found in VH , the distance of the observer's eye above the plane of the ground will always be shown by the distance between VH and VH_1 .

45. To find the perspective of the point a , Fig. 10, draw the visual ray through the point, and find where this visual ray pierces the picture plane (§ 24*f*). The horizontal projection of the visual ray is shown by the line R^H drawn through the horizontal projection SP^H of the observer's eye and the horizontal projection a^H of the point a . The vertical projection of the visual ray is shown by the line R^V drawn through the vertical projection SP^V of the observer's eye and the vertical projection a^V of the point a . This visual ray pierces the picture plane at the point a^P on R^V vertically in line with the point where

R^H crosses HPP (§§ 35 and 36). a^P is the perspective of the point a .

NOTE. — To find where any line, represented by its horizontal and vertical projections, pierces the picture plane, is one of the most used and most important problems in perspective projection. The point where any line pierces the picture plane will always be found on the vertical projection of the line, vertically above or below the point where the horizontal projection of the line crosses HPP (§§ 35 and 36).

NOTATION.

46. In order to avoid confusion between the vertical, horizontal, and perspective projections of the points and lines in the drawing, it becomes necessary to adopt some systematic method of lettering the different points and lines. The following method will be found convenient, and has been adopted in these notes.

If the student will letter each point or line as it is found, in accordance with this notation, he will be able to read his drawings at a glance, and any desired projection of a point or line may be recognized instantly.

The *picture plane* (or vertical coordinate) is indicated by the capital letters PP.

The *plane of the horizon* (or horizontal coordinate) is indicated by the capital letter H.

A *point* in space is indicated by a small letter.

The same small letter with an index V , H , or P , indicates its *vertical*, *horizontal*, or *perspective projection*, respectively.

A *line* in space is indicated by a capital letter, usually one of the first letters in the alphabet.

The same capital letter with an index V , H , or P , indicates its *vertical*, *horizontal*, or *perspective projection*, respectively.

All lines which belong to the same system may be designated by the same letter, the different lines being distinguished by the subordinate 1 , 2 , 3 , etc., placed after the letter.

The *trace of a plane upon the picture plane* is indicated by a capital letter (usually one of the last letters in the alphabet) with a capital V placed before it.

The same letter preceded by a capital **H** indicates the trace of the plane upon the horizontal coordinate.

The perspective of the vanishing trace of a system of planes is indicated by a capital letter preceded by a capital **T**.

The perspective of the vanishing point of a system of lines is indicated by a small *v* with an index corresponding to the letter of the lines which belong to the system.

PP = vertical coordinate, or picture plane.

HPP = horizontal trace of the vertical coordinate, or picture plane.

H = horizontal coordinate, or plane of the horizon.

VH = vertical trace of the horizontal coordinate, or plane of the horizon.

H₁ = plane of the ground.

VH₁ = vertical trace of the plane of the ground.

a = point in space.

a^V = vertical projection of the point.

a^H = horizontal projection of the point.

a^P = perspective projection of the point.

A = line in space.

A^V = vertical projection of the line.

A^P = perspective projection of the line.

VS = trace of the plane **S** upon **PP** (vertical trace).

HS = trace of the plane **S** upon **H** (horizontal trace).

TS = perspective of the vanishing trace of the plane **S**. (See Note 1 below.)

v^A = perspective of the vanishing point of a system of lines, the elements of which are lettered **A₁**, **A₂**, **A₃**, **A₄**, etc. (See Note 2 below.)

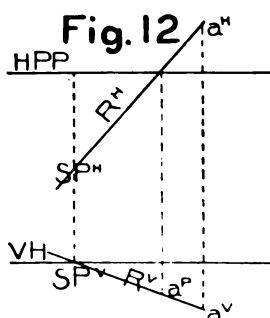
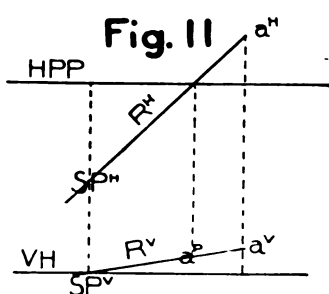
NOTE 1. -- A plane in space may also be designated by the letters of any two lines which lie in it. Thus, the plane **AB** would be a plane determined by the two lines **A** and **B**. **TAB** would indicate the perspective of the vanishing trace of the plane.

NOTE 2. -- A straight line may be designated by the letters of any two points which lie in it. Thus, the line *ab* would be a straight line determined by the two points *a* and *b*. *v^{ab}* would indicate the perspective of the vanishing point of the line. It is sometimes convenient to use this notation in place of the general one.

ELEMENTARY PROBLEMS.

47. PROBLEM I. Fig. 11. To find the perspective of a point. The point to be situated $\frac{1}{4}$ " behind the picture plane, and $\frac{1}{8}$ " above the plane of the horizon. The observer's eye to be $\frac{1}{2}$ " in front of the picture plane.

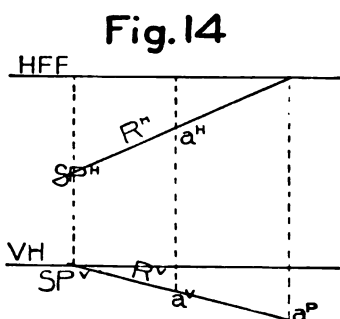
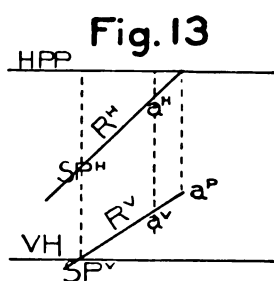
First assume HPP and VH (§ 40). These lines may be drawn anywhere on the paper, HPP usually being placed some distance above VH, in order to avoid confusion between horizontal and vertical projections. The position of the point with respect to the coordinate planes must now be established by means of its vertical and horizontal projections. a^v located $\frac{1}{8}$ " above VH will represent the vertical projection of the point. Its horizontal projection must be vertically in line with a^v ; and since the point



is to be $\frac{1}{4}$ " behind the picture plane, its horizontal projection must be $\frac{1}{4}$ " behind the horizontal projection of the picture plane, i.e., $\frac{1}{4}$ " behind HPP. Next establish the position of the observer's eye, or station point. Its vertical projection (SP^v) may be assumed anywhere in VH. Its horizontal projection (SP^h) must be vertically in line with SP^v and $\frac{1}{2}$ " in front of HPP. The perspective of the point a will be where the visual ray through the point pierces the picture plane. A line R^h drawn through SP^h and a^h will be the horizontal projection of this visual ray. Its vertical projection will be the line R^v drawn through SP^v and a^v . The perspective a^p of the point will be found on R^v vertically in line with the intersection of R^h and HPP (§ 45, note). Compare with the construction shown in Fig. 10 and Fig. 8.

48. Figs. 12, 13, and 14 illustrate this same problem.

In Fig. 12, the point a , as shown by its vertical and horizontal projections, is situated $\frac{1}{4}$ " below the plane of the horizon and $\frac{1}{4}$ " behind the picture plane. a^P is the perspective of the point.

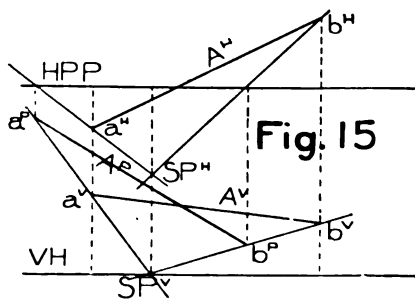


In Fig. 13, the point a is $\frac{1}{4}$ " above the plane of the horizon and $\frac{1}{8}$ " in front of the picture plane. a^P is its perspective.

In Fig. 14, the point a is $\frac{1}{8}$ " below the plane of the horizon and $\frac{1}{4}$ " in front of the picture plane. a^P is its perspective.

49. PROBLEM II. Fig. 15. To find the perspective of a line, the line being determined by its vertical and horizontal projections.

Let HPP and VH be given as indicated in the figure. Let A^H represent the horizontal projection of the line, its two extremities being represented by a^H and b^H , respectively. Similarly, let A^V be the vertical projection of the line, a^V and b^V being the vertical projections of its extremities. Let the position of the observer's eye be as indicated by SP^V and SP^H .

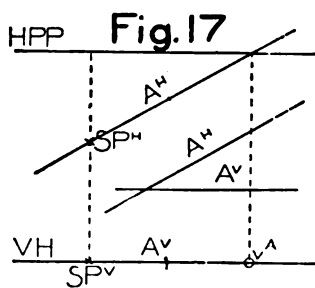
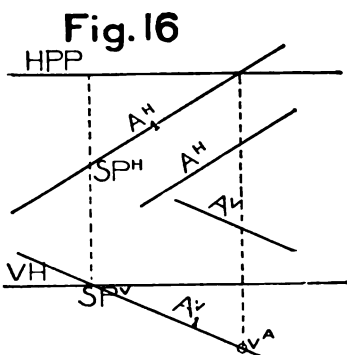


The perspective of the point a has been found by Problem I. at a^P . The per-

spective of the point b has been found by Problem I. at b^P . The line (A^P), joining a^P and b^P , will be the perspective of the given line. (See note under § 23.)

50. PROBLEM III. Fig. 16. Having given the vertical and horizontal projection of any line, to find the perspective of its vanishing point.

Let the line be given by its vertical and horizontal projections (A^V and A^H), as indicated in the figure. SP^V and SP^H represent the position of the observer's eye. To find the perspective of the

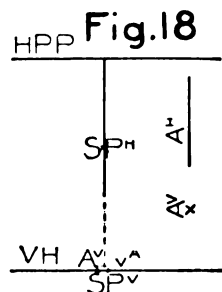


vanishing point of any line, draw through the observer's eye an element of the system to which the line belongs, and find where this element pierces the picture plane (§ 24 *g*). Through SP^H draw A_1^H parallel to A^H , and through SP^V draw A_1^V parallel to A^V . A_1^H and A_1^V represent the two projections of a line passing through the observer's eye and parallel to $A^H A^V$. This line pierces the picture plane at v^A , giving the perspective of the required vanishing point (§ 45, note). The perspectives of all lines parallel to $A^H A^V$ will meet at v^A .

Figs. 17 and 18 illustrate this same problem.

51. In Fig. 17, the line, as shown by its two projections, is a horizontal one; hence, A_1^H drawn through SP^H coincides with VH , and the vanishing point for the system of the lines must be found on VH at v^A , as indicated (§ 24 *c*).

NOTE. — Systems of lines which vanish upward will have their vanishing points above VH . Systems of lines which vanish downward will have their vanishing points below VH (§ 16).



52. In Fig. 18, the given line is perpendicular to the picture plane; hence, A_1^V must be a point coincident with SP^V ; and as v^A will always be found on A_1^V , the vanishing point of the line must coincide with SP^V .

NOTE. — In a perspective drawing, the vanishing point for a system of lines perpendicular to the picture plane will always coincide with the vertical projection of the observer's eye.

METHOD OF THE REVOLVED PLAN.

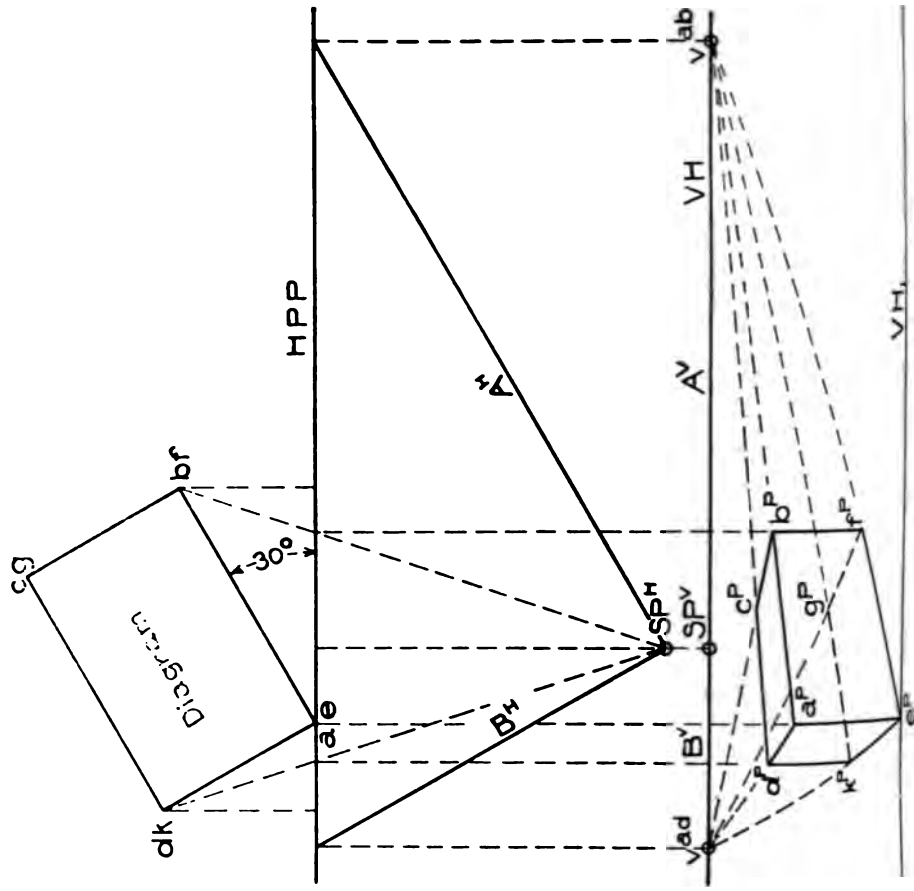
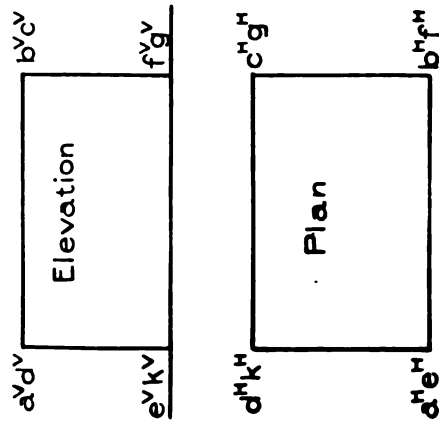
53. PROBLEM IV. Fig. 19. To find the perspective of a rectangular block resting upon a horizontal plane 1" below the level of the eye, and turned so that the long side of the block makes an angle of 30° with the picture plane.

The block is shown in plan and elevation at the left of the figure. The first step will be to make an auxiliary horizontal projection of the block on the plane of the horizon, showing the exact position of the block as it is to be seen in the perspective projection. This auxiliary horizontal projection is really a revolved plan of the object, and is called a **Diagram**. It is the general rule, in making a perspective projection, to place the object behind the picture plane with one of its principal vertical lines lying in the picture plane (24 *h*). HPP is usually drawn near the upper edge of the paper, leaving just room enough behind to place the auxiliary plan or diagram. In the figure the diagram is shown in the required position, i.e., with one of its long sides ($abfc$) making an angle of 30° with the picture plane. The vertical edge (ae) of the block is supposed to lie in the picture plane. VH may now be drawn parallel to HPP at any convenient distance from it, as indicated. VH_1 , the vertical trace of the plane on which the block is supposed to rest, should be assumed in accordance with the given data, i.e., 1" below VH (§ 44).

The position of the observer's eye should next be established. SP^H is its horizontal projection, and shows by its distance from HPP the distance in front of the picture plane at which the observer is supposed to stand. SP^V is its vertical projection, and must always be found in VH. In this problem the station point is $1\frac{1}{2}$ " in front of the picture plane.



9/19



NOTE. — As a general rule, it is well to assume the station point on a vertical line half way between two lines dropped from the extreme edges of the diagram, as indicated. This is not necessary, but, as will be explained later, it usually insures a more pleasing perspective projection.

Next find the vanishing points for the different systems of lines in the object (§ 12). There are three systems of lines in the block, formed by its three sets of parallel edges.

1st. A system formed by the four horizontal edges vanishing to the right: *ab*, *ef*, *dc*, and *kg*.

2d. A system formed by the four horizontal edges vanishing towards the left: *ad*, *ek*, *bc*, and *fg*.

3d. A system formed by the four vertical edges.

First find the vanishing point for the system parallel to *ab* by drawing through the station point a line parallel to *ab* and finding where it pierces the picture plane (24 *g*). A'' drawn through SP'' is the horizontal projection of such a line. Its vertical projection (A^v), drawn through SP^v , will coincide with VH , and its vanishing point will be found on VH at v^{ab} (§ 51). All lines in the perspective of the object that are parallel to *ab* will meet at v^{ab} (§ 24 *a*). In a similar manner find v^{ad} , which will be the vanishing point for all lines parallel to *ad*.

54. If the method for finding any vanishing point is applied to the system of vertical lines, it will be found that this vanishing point will lie vertically over SP^v at infinity. That is to say, since all vertical lines are parallel to the picture plane, if a vertical line is drawn through the station point, it will never pierce the picture plane. Therefore (24 *g*), the perspective of the vanishing point of a vertical line cannot be found within any finite limits, but will be *vertically over SP^v , and at an infinite distance from it*. In a perspective projection *all vertical lines are drawn actually vertical, and not converging towards one another*.

NOTE. — This is true of all lines in an object which are *parallel to the picture plane*. Thus, *the perspective of any line which is parallel to the picture plane, will actually be parallel to the line itself; and the perspectives of the elements of a system of lines parallel to the picture plane, will be drawn parallel to, and not converging towards, one another*. That this must be so, is evident,

since, if the perspectives of such a system of lines did converge towards one another, they would meet within finite limits. But it has just been found that the perspective of the vanishing point of such a system is at infinity. The perspectives of the elements of any system can meet only at the perspective of their vanishing point, and must, therefore, in a system parallel to the picture plane, be drawn parallel to one another.

The directions of the perspectives of all lines in the object have now been determined, and will be as follows:

All lines parallel to ab will meet at v^{ab} .

All lines parallel to ad will meet at v^{ad} .

All vertical lines will be drawn vertical.

Since the point e is in the base of the object, it lies on the plane of the ground, and also, since the line ae lies in the picture plane, the point e must lie on the intersection of the plane of the ground with the picture plane. Therefore, the point e must lie in VH_1 , and must be vertically under the point e in the diagram. Since the point e lies in the picture plane, it will be its own perspective; and e^p will be found on VH_1 , vertically under e in the diagram, as shown in the figure. From e^p the perspective of the lower edges of the cube will vanish at v^{ab} and v^{ad} , respectively, as indicated.

f^p is the perspective of the point f , and will be found on the lower edge of the block, vertically under the intersection of HPP with the horizontal projection of the visual ray drawn through the point f in the diagram.

Similarly, k^p is found on the lower edge of the block, vertically under the intersection of HPP and the visual ray drawn through the point k in the diagram.

Vertical lines drawn through f^p , e^p , and k^p , will represent the perspectives of the visible vertical edges of the block.

The edge $e^p a^p$ being in the picture plane will be its own perspective, and show in its true size (§ 24 h). Therefore, a^p may be established by making the distance $e^p a^p$ equal to $e^v a^v$ as taken from the given elevation. From a^p two of the upper horizontal edges of the block will vanish at v^{ab} and v^{ad} , respectively, establishing the points b^p and d^p , by their intersections with the vertical edges drawn through k^p and f^p , respectively. Lines drawn through

d^P and b^P , and vanishing respectively at v^{ab} and v^{ad} , will intersect at c^P , and complete the perspective of the block.

Before going farther in the notes, the student should solve the problems on Plate I.

LINES OF MEASURES.

55. Any line which lies in the picture plane will be its own perspective, and show the true length of the line (24 *h*). Such a line is called a **Line of Measures**.

In the last problem, the line ae , being in the picture plane, was a line of measures; that is to say, its length could be laid off directly from the given data, and from this length the lengths of the remaining lines in the perspective drawing could be established. Fig. 20 shows a similar problem. The line ae lies in the picture plane, and $a^P e^P$ is, therefore, a line of measures for the object.

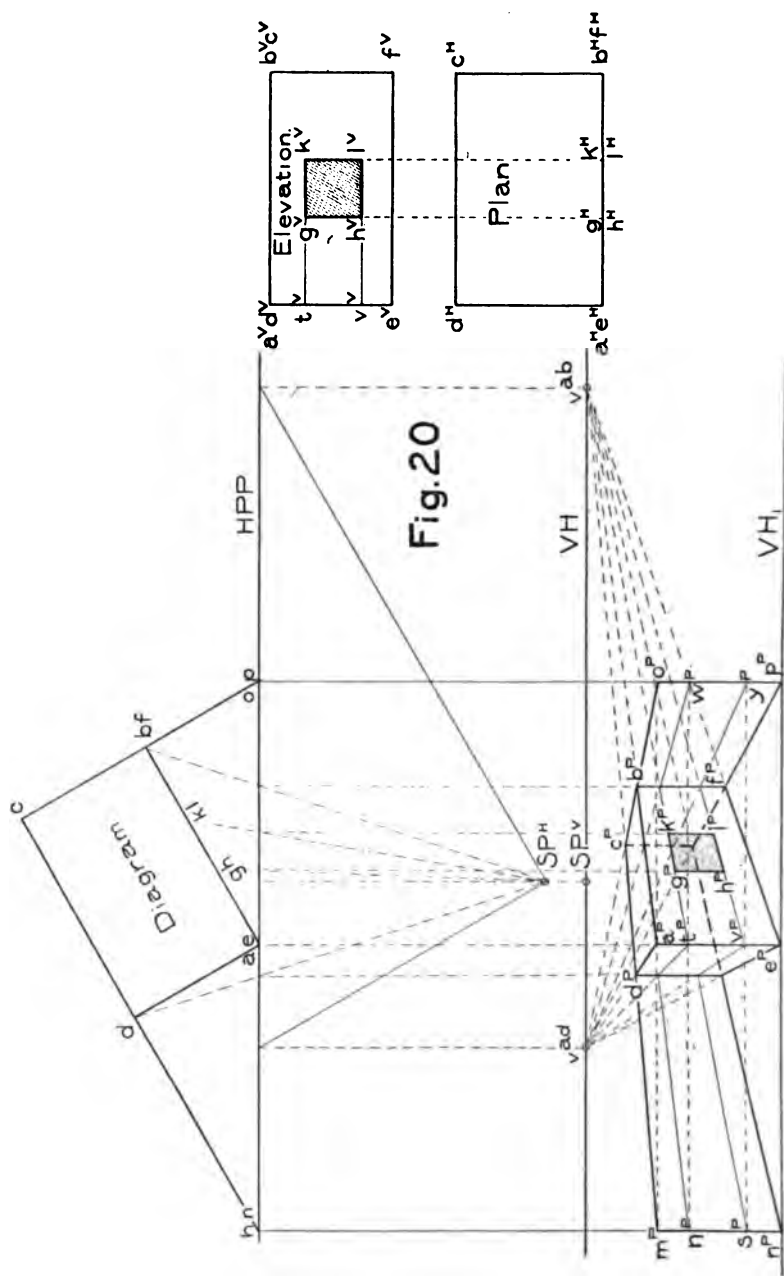
56. Besides this principal line of measures, other lines of measures may easily be established by extending any vertical plane in the object until it intersects the picture plane. This intersection, since it lies in the picture plane, will show in its true size, and will be an **auxiliary line of measures**. All points in it will show at their true height above the plane of the ground. Thus, in Fig. 20, $a^P e^P$ is the principal line of measures, and shows the true height of the block. If the rear vertical faces of the block are extended till they intersect the picture plane, these intersections ($m^P n^P$ and $o^P p^P$) will be auxiliary lines of measures, and will also show the true height of the block. It will be noticed in the figure that $m^P n^P$ and $o^P p^P$ are each equal to $a^P e^P$. Either one of these lines could have been used to determine the vertical height of the perspective of the block. For illustration, suppose it is desired to find the height of the perspective, using the line $o^P p^P$ as the line of measures. Assume the vanishing points (v^{ad} and v^{ab}) for the two systems of horizontal edges in the block to have been established as in the previous case. Now extend the line be (in the diagram), which represents the horizontal projection of the face cbf , till it intersects HPP. From this intersection drop a vertical line op which will represent the intersection of the vertical face cbf with the picture plane, and will be a line of measures for the face. p^P , where this line of measures intersects VH_1 , will be the

point where the lower horizontal edge (produced) of the face cbf intersects the picture plane. Measure off the distance $p^p o^p$ equal to the true height of the block, as given by the elevation. Two lines drawn through o^p and p^p respectively, and vanishing at v^{ab} , will represent the perspectives of the upper and lower edges of the face cbf , produced. The perspective (b^p), of the point b , will be found on the perspective of the upper edge of the face cbf , vertically below the intersection of HPP with the horizontal projection of a visual ray drawn through the point b in the diagram. A vertical line through b^p will intersect the lower horizontal edge of the face cbf in the point f^p . Lines drawn respectively through b^p and f^p , vanishing at v^{ab} , will establish the perspectives of the upper and lower horizontal edges of the face $abfe$. The points a^p and e^p will be found vertically under the points a and e in the diagram. The remainder of the perspective projection may now easily be determined.

57. The perspectives of any points on the faces of the block may be found by means of the diagram and one of the lines of measures.

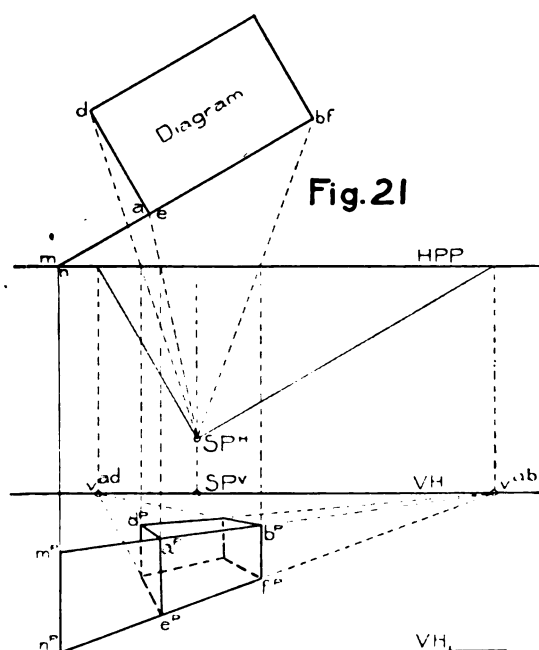
Let the points g^v , h^v , k^v , and l^v , in the given elevation, determine a square on the face $abfe$ of the block. Let the points g , h , k , and l , represent the position of the square in the diagram. Extend the upper and lower horizontal edges of the square, as shown in elevation, until they intersect the vertical edge $a^v e^v$ in the points t^v and r^v . To determine the perspective of the square, lay off on $a^p e^p$, which is a line of measures for the face $abfe$, the divisions t^p and r^p taken directly from the elevation. Two lines drawn through t^p and r^p respectively, vanishing at v^{ab} , will represent the perspectives of the upper and lower edges (produced) of the square. g^p will be found on the perspective of the upper edge, vertically under the intersection of HPP with the horizontal projection of a visual ray drawn through the point g in the diagram. The position of k^p may be established in a similar manner. Vertical lines drawn through g^p and k^p respectively, will complete the perspective of the square.

58. The auxiliary line of measures $o^p p^p$ might have been used instead of $a^p e^p$. In this case, $o^p p^p$ should be divided by the points w^p and y^p , in the same way that ae , in elevation, is divided



by the points t and r . Through w^p and y^p , draw horizontal lines lying in the plane cbf , for which $o^p p^p$ is a line of measures. These lines will vanish at v^{ad} , and intersect the vertical edge $b^p f^p$ of the block. From these intersections draw horizontal lines lying in the plane $abef$, vanishing at v^{ab} , and representing the upper and lower edges of the square. The remainder of the square may be determined as in the previous case.

In a similar manner, the auxiliary line of measures $m^p n^p$ might have been used to determine the upper and lower edges of



the square. This construction has been indicated, and the student should follow it through.

59. It sometimes happens that no line in the object lies in the picture plane. In such a case there is no principal line of measures, and some vertical plane in the object must be extended until it intersects the picture plane, forming by this intersection an auxiliary line of measures. Fig. 21 illustrates such a case. A rectangular block, similar to those shown in Figs. 19 and 20, is

situated some distance behind the picture plane, as indicated by the relative positions of HPP and the diagram.

Its perspective projection will evidently be smaller than if the vertical edge ae were in the picture plane, as was the case in Figs. 19 and 20, and the perspective of ae will evidently be shorter than the true length of ae . There is, therefore, no line in the object that can be used for a line of measures. It becomes necessary to extend one of the vertical faces of the block until it intersects the picture plane, and shows by the intersection its true vertical height. Thus, the plane $abfe$ has been extended, as indicated in the diagram, until it intersects the picture plane in the line mn . This intersection is an auxiliary line of measures for the plane $abfe$, and $m^p n^p$ shows the true vertical height of this plane.

Either of the other vertical faces of the block, as well as the face $abfe$, might have been extended until it intersected the picture plane, and formed by this intersection a line of measures for the block.

The vanishing points for the various systems of lines have been found as in the previous cases.

From m^p and n^p , the horizontal edges of the face $abfe$ vanish to e^{ab} . a^p will be found on the upper edge of this face, vertically below the intersection of HPP with the horizontal projection of the visual ray through the point a in the diagram. A vertical line through a^p will represent the perspective of the nearest vertical edge of the block, and will establish the position of e^p .

In a similar manner, b^p will be found vertically below the intersection of HPP with the horizontal projection of the visual ray through the point b in the diagram. A vertical line through b^p will establish f^p , and complete the perspective of the face $abfe$. Having found the perspective of this face, the remainder of the block may be determined as in the previous problems.

NOTE. — Instead of being some distance behind the picture plane, the block might have been wholly or partly in front of the picture plane. In any case, find the intersection with the picture plane of some vertical face of the block (produced, if necessary). This intersection will show the true vertical height of the block.

At this point the student should solve Plate II.

60. PROBLEM V. Fig. 22. To find the perspective of a house, the projections of which are given.

The plan, front, and side elevations of the house are shown in the figure. The side elevation corresponds to the projection on the profile plan, used in the study of projections. This problem is a further illustration of the method of revolved plan and of the use of horizontal vanishing points and auxiliary lines of measures. It is very similar to the three previous problems on the rectangular blocks.

The first step in the construction of the perspective projection is to make a diagram (§ 53) which shall show the horizontal projections of all the features that are to appear in the drawing. The diagram should be placed at the top of the sheet, and turned so that the sides of the house make the desired angles with the picture plane. In Fig. 22 the diagram is shown with the long side making an angle of 30° with the picture plane. The roof lines, the chimney, and the positions of all windows, doors, etc., that are to be visible in the perspective projection, will be seen marked on the diagram.

The nearest vertical edge of the house is to lie in the picture plane. This is indicated by drawing HPP through the corner of the diagram which represents this nearest edge.

VH may be chosen at any convenient distance below HPP.

The position of the station point is shown in the figure by its two projections SP^V and SP^H . SP^V must always be in VH. The distance between SP^H and HPP shows the distance of the observer's eye in front of the picture plane (§ 43).

v^{ab} and v^{ad} may be found as in the preceding problems.

The position of the plane on which the object is to rest should next be established by drawing VH_1 , the distance between VH and VH_1 showing the height of the observer's eye above the ground (§ 44).

In addition to the plane of the ground represented by VH_1 , a second ground plane, represented by VH_2 , has been chosen some distance below VH_1 . In the figure, two perspective projections have been found, one resting on each of these two ground planes. The perspective which rests upon the plane represented by VH_2 shows the house as though seen by a man standing with

nearly on a level with the tops of the windows (§ 29). The view which rests on the plane represented by VH_2 shows a bird's-eye view of the house, in which the eye of the observer (always in VII) is at a distance above the plane on which the view rests, equal to about two and one-half times the height of the ridge of the house above the ground.

These two perspective projections illustrate the effect of changing the distance between VH and the vertical trace (§ 34, note) of the plane on which the perspective projection is supposed to rest. The construction of both views is exactly the same. The following explanation applies to both equally well, and the student may consider either in studying the problem.

61. We will first neglect the roof of the house, and of the porch. The remaining portion of the house will be seen to consist of two rectangular blocks, one representing the main body of the house, and the other representing the porch.

The block representing the main part of the house occupies a position exactly similar to that of the block shown in Fig. 19. First consider this block irrespective of the remainder of the house. A vertical line dropped from the corner of the diagram that lies in HPP will be a measure line for the block, and will establish, by its intersection with VH_1 (or VH_2), the position of the point e^p , in exactly the same way that the point e^p in Fig. 19 was established. $e^p a^p$ shows the true height of the part of the house under consideration, and should be made equal to the corresponding height $a^v e^v$, as shown by the elevations. The rectangular block representing the main part of the house may now be drawn exactly as was the block in Fig. 19, Problem IV.

62. Having found the perspective of the main part of the house, the porch (without its roof) may be considered as a second rectangular block, no vertical edge of which lies in the picture plane. It may be treated in a manner exactly similar to that of the block shown in Fig. 21, § 59. We may consider that the *rear* vertical face of the block, which forms the porch of the house (g, g), has been extended until it intersects the picture plane in the line ac , giving a line of measures for this face, just as in Fig. 21 the *nearest* vertical face of the block was extended until it intersected the picture plane in the line of measures mn .

On $e^p a^p$, make $e^p c^p$ equal to the true height of the vertical wall of the porch, as given by the elevation. A line through c^p , vanishing at v^{ab} , will be the perspective of the upper horizontal edge of the rear face of the block which forms the porch. The line through e^p , vanishing at v^{ab} , which forms the lower edge of the front face of the main body of the house, also forms the lower edge of the rear face of the porch. Through the point h in the diagram, draw a visual ray, and through the intersection of this visual ray with HPP drop a vertical line. Where this vertical line crosses the upper and lower horizontal edges of the rear face of the porch, will establish the points g^p and h^p respectively. Having found the vertical edge $g^p h^p$, the remainder of the perspective of the porch (except the roof) can be found without difficulty, the horizontal edges of the porch vanishing at either v^{ab} or v^{ad} , according to the system to which they belong. Each vertical edge of the porch will be vertically below the point where HPP is crossed by a visual ray drawn through the point in the diagram which represents that edge. The fact that the porch projects, in part, in front of the picture plane, as indicated by the relation between the positions of the diagram and HPP, makes absolutely no difference in the construction of the perspective projection.

All of the vertical construction lines have not been shown in the figure, as this would have made the drawing too confusing. The student should be sure that he understands how every point in the perspective projection has been obtained, and, if necessary, should complete the vertical construction lines with pencil.

63. Having found the perspective of the vertical walls of the main body of the house, and of the porch, the next step will be to consider the roof of the main part of the house.

Imagine the horizontal line tw , which forms the ridge of the roof, to be extended until it intersects the picture plane. This is shown on the diagram by the extension of the line tw until it intersects HPP. From this intersection drop a vertical line, as indicated in the figure. This vertical line may be considered to be the line of measures for an imaginary vertical plane passing through the ridge of the house, as indicated by the dotted lines in the plan and elevations of the house. On this line of meas-

ures, lay off the distance nm measured from VH_1 (or VH_2), equal to the true height of the ridge above the ground as given by the elevations of the house. A line drawn from the point m , vanishing at v^{ab} , will represent the ridge of the house, indefinitely extended. From the points t and w in the diagram draw visual rays. From the intersections of these visual rays with HPP drop vertical lines which will establish the positions of t^p and w^p on the perspective of the ridge of the roof. Lines drawn from t^p and w^p to the corners of the vertical walls of the house, as indicated, will complete the perspective of the roof.

To find the perspective of the porch roof, draw a visual ray through the point y on the diagram, and from its intersection with HPP drop a vertical. Where this vertical crosses the line $a^p b^p$ will give y^p , one point in the perspective of the ridge of the porch. The perspective of the ridge will be represented by a line through y^p , vanishing at v^{ad} . The point z^p in the ridge will be vertically below the intersection of HPP with the visual ray drawn through the point z on the diagram. Lines drawn from y^p and z^p to the corners of the vertical walls of the porch, as indicated, will complete the perspective of the porch roof.

64. The perspective of the chimney must now be found. It will be seen that the chimney is formed by a rectangular block; and if it is supposed to extend down through the house, and rest upon the ground, it will be a block under exactly the same conditions as the one shown in Fig. 21, § 59. In order to find its perspective, extend its front vertical face, as indicated on the diagram, till it intersects HPP. A vertical line dropped from this intersection will be a line of measures for the front face of the chimney, and the distance ps , laid off on this line from VH_1 (or VH_2), will show the true height of the top of the chimney above the ground, as given on the elevation. The distance so , measured from the point s on the line of measures, will be the true vertical height of the face of the chimney that is visible above the roof. Lines through s and o , vanishing at v^{ab} , will represent the horizontal edges of the front visible face of the chimney. The vertical edges of this face will be found vertically below the points where HPP is crossed by the visual rays drawn through the horizontal projections of these edges on the diagram.

Having determined the perspective of the front face of the chimney, the perspectives of the remaining edges may be found as in the cases of the rectangular blocks already discussed. From the point r in the diagram, where the ridge of the roof intersects the left hand vertical face of the chimney, draw a visual ray intersecting HPP, and from this intersection drop a vertical line to the perspective of the ridge of the house, giving the perspective (r^p) of the point where the ridge intersects the left hand face of the chimney. A line drawn from r^p to the nearest lower corner of the front face of the chimney will be the perspective of the intersection of the plane of the roof with the left hand face of the chimney.

65. The problem of finding the perspectives of the windows and door is exactly similar to that of finding the perspective of the square $hgkl$ on the surface of the block shown in Fig. 20.

It will be noticed that the intersection with the picture plane of the left hand vertical face of the porch gives a line of measures (§ 55 and § 59, note) for this face. This line may be used conveniently in establishing the height of the window in the porch.

At this point in the course the student should solve Plate III.

VANISHING POINTS OF OBLIQUE LINES.

66. The perspective of the house in the last problem was completely drawn, using only the vanishing points for the two principal systems of horizontal lines. By this method it is possible to find the perspective projection of any object. But it is often advisable, for the sake of greater accuracy, to determine the vanishing points for systems of oblique lines in the object, in addition to the vanishing points for the horizontal systems.

Take, for example, the lines $g^p y^p$ and $x^p z^p$ in Fig. 22. The perspective projections of these two lines were obtained by first finding the points g^p , y^p , x^p , and z^p , and then connecting g^p with y^p , and x^p with z^p . As the distances between g and y , and x and z , are very short, a slight inaccuracy in determining the positions of their perspectives might result in a very appreciable inaccuracy in the directions of the two lines $g^p y^p$ and $x^p z^p$. These two lines

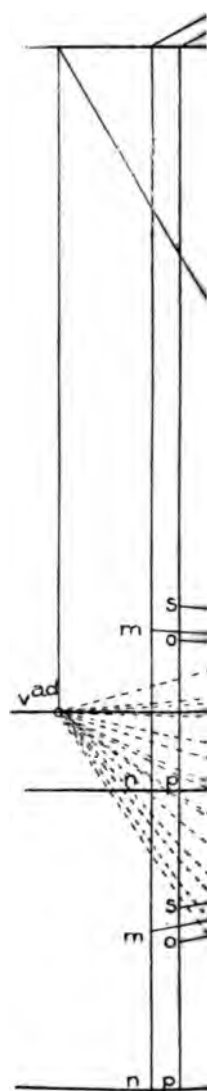
belong to the same system, and should approach one another as they recede. Unless the points which determine them are found with great care, the two lines may approach too rapidly, or even diverge, as they recede from the eye. In the latter case, the drawing would be absolutely wrong in principle, and the result would be very disagreeable to the trained eye. If, however, the perspective of the vanishing point of the system to which these two lines belong, can be found, and the two lines be drawn to meet at this vanishing point, the result will necessarily be accurate.

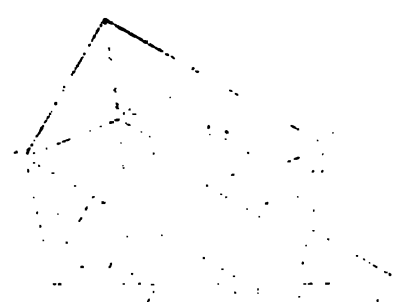
The line through r'' , which forms the intersection between the roof of the house and the left hand face of the chimney, is a still more difficult one to determine accurately. Its length is so short that it is almost impossible to establish its exact direction from the perspective projections of its extremities. If the perspective of its vanishing point can be found, however, its direction at once becomes definitely determined.

67. It is not a difficult matter to find the perspective of the vanishing point for each system of lines in an object. The method is illustrated in Fig. 23. The general method for finding the perspective of the vanishing point for any system of lines has already been stated in § 24 *g*, and illustrated in Figs. 16, 17, and 18, §§ 50, 51, and 52. It remains only to adapt the general method to a particular problem, such as that shown in Fig. 23.

The plan and elevation of a house are given at the left of the figure. The diagram has been drawn at the top of the sheet, turned at the desired angle. The assumed position of the station point is indicated by its two projections, SP^V and SP^H . VH necessarily passes through SP^V .

68. In order to find the perspective of the vanishing point of any system of lines, the vertical and horizontal projections of some element of the system must be known (see method of Problem III.). The diagram gives the horizontal projection of every line in the object which is to appear in the perspective projection. The diagram, however, has been turned through a certain horizontal angle in order to show the desired perspective view, and there is no revolved elevation to agree with the revolved position of the diagram. A revolved elevation could, of course, be con-





Section



structed by revolving the given plan of the object until all its lines were parallel to the corresponding lines in the diagram, and then finding the revolved elevation of the object corresponding to the revolved position of the plan.

NOTE. — The method of constructing a revolved elevation has been explained in detail in the Instruction Paper on Mechanical Drawing, Part III., Page 12.

Having constructed the revolved plan and elevation of the object to agree with the position of the diagram, we should then have the vertical and horizontal projections of a line parallel to each line that is to appear in the perspective drawing, and the method of Problem III. could be applied directly.

This is exactly the process that will be followed in finding the vanishing points for the oblique lines in the object, except that instead of making a complete revolved plan and elevation of the house, each system of lines will be considered by itself, and the revolved plan and elevation of each line will be found as it is needed, without regard to the remaining lines in the object.

69. All the lines in the house belong to one of eleven different systems that may be described as follows: —

A vertical system, to which all the vertical lines in the house belong. The perspective of the vanishing point of this system cannot be found within finite limits (§ 54).

Two horizontal systems parallel respectively to *ab* and *ad* (see diagram). The perspectives of the vanishing points of these systems will be found in VII (§ 24 *c*, note).

Five systems of lines vanishing upward, parallel respectively to *af*, *bg*, *mn*, *on*, and *hk* (see diagram). The perspectives of the vanishing points of these systems will be found to lie above VII (§ 51, note).

Three systems of lines vanishing downward, parallel respectively to *fd*, *gc*, and *kl* (see diagram). The perspectives of the vanishing points of these systems will be found below VII (§ 51, note).

NOTE. — To determine whether a line vanishes upward or downward, proceed as follows: —

Examine the direction of the line as shown in the *diagram*. Determine which end of the line is the farther behind the picture plane. If the *more distant* end of the line is *above* the nearer end, the line vanishes *upward*, and the perspective of its vanishing point will be found above VII.

If, on the other hand, the *more distant* end of the line is *lower* than the nearer end, the line vanishes *downward*, and the perspective of its vanishing point will be found below VII.

For illustration, consider the line *bg*. The diagram shows the point *g* to be farther behind the picture plane than the point *b*, while the given elevation shows the point *g* to be higher than the point *b*. Therefore the line *rises* as it *recedes*, or, in other words, it *vanishes upward*.

In the case of the line *fd*, the diagram shows the point *d* to be farther behind the picture plane than the point *f*, while the elevation shows the point *d* to be lower than the point *f*. Therefore the line must vanish downward, and its vanishing point be found below VII.

If the horizontal projection of a line, as shown by the diagram, is parallel to HPP, the line itself is parallel to the picture plane, and the perspective of its vanishing point cannot be found within finite limits (§ 54, note). *The perspective projections of such a*

system of lines will show the true angle which the elements of the system make with the horizontal coordinate.

70. The construction for the vanishing points in Fig. 23 is shown by dot and dash lines.

The vanishing points for the two systems of horizontal lines have been found at v^{ab} and v^{ad} respectively, as in the preceding problems.

Next consider the line af . The first step is to construct a revolved plan and elevation of this line to agree with the position of the diagram. Revolve the horizontal projection ($a^H f^H$) of the line in the given plan about the point f^H , until it is parallel to the line af in the diagram. During this revolution, the point f^H remains stationary, while the point a^H describes a horizontal arc, until $a^H f^H$ has revolved into the position shown by the red line $a_1^H f^H$, which is parallel to the line af in the diagram. The vertical projection $a^V f^V$ must, of course, revolve with the horizontal projection. The point f^V remains stationary, while the horizontal arc described by the point a shows in vertical projection as a horizontal line. At every point of the revolution the vertical projection of the point a must be vertically in line with its horizontal projection. When a^H has reached the position a_1^H , a^V will be vertically above a_1^H at the point a_1^V , and $a_1^V f^V$ will be the revolved elevation of the line.

We now have the vertical and horizontal projections ($a_1^V f^V$ and $a_1^H f^H$) of an element of the system to which the roof line, represented in the diagram by af , belongs. The vanishing point of this system may be determined as in Problem III. Draw through SP^H a line parallel to $a_1^H f^H$ (or af in the diagram), representing the horizontal projection of the visual element of the system. Draw through SP^V a line parallel to $a_1^V f^V$, representing the vertical projection of the visual element of the system. The visual element, represented by the two projections just drawn, pierces the picture plane at v^{af} (§ 45, note), giving the perspective of the vanishing point for the roof line, represented by af in the diagram.

In a similar manner the vanishing point for the roof line, represented in the diagram by bg , may be determined. First find, from the given plan and elevation of the object, a revolved plan

and elevation of bg , to agree with the position of the line in the diagram. Revolve $b''g''$ in the given plan about the point g'' , until it is parallel to bg in the diagram, and occupies the position indicated by the line $b_1''g''$. The corresponding revolved elevation is represented by the red line $b_1'g'$.

$b_1''g''$ and $b_1'g'$ now represent respectively the horizontal and vertical projections of an element of the system to which the roof line, represented by bg in the diagram, belongs. The vanishing point of this system can be found by Problem III. Through SP'' draw a line parallel to $b_1''g''$ (or bg in the diagram), representing the horizontal projection of the visual element of the system; and through SP' draw a line parallel to $b_1'g'$, representing the vertical projection of their visual element. The visual element, represented by these two projections, pierces the picture plane at $v''g'$, giving the perspective of the vanishing point of the roof line, represented in the diagram by the line bg .

By a similar process, $h''k''$ and $h'k'$ are found to represent respectively the horizontal and vertical projections of an element of the system to which belongs the roof line represented in the diagram by the line hk . The perspective of the vanishing point of this line has been found at $v''hk'$.

$v''af$, $v''bg$, and $v''hk$ have all been found to lie above VII (§ 51. note).

71. $v''fd$, $v''ge$, and $v''kl$ are found exactly as were $v''af$, $v''bg$, and $v''hk$; but, as the systems to which they belong vanish downward, they will lie below VII (§ 51, note).

Thus, $f''d_1''$ and $f'v'd_1'$ are respectively the horizontal and vertical projections of an element of the system represented by fd in the diagram. A line drawn through SP'' , parallel to $f''d_1''$ (or $f'd$ in the diagram), will intersect HPP in the point w . A vertical line through w will intersect a line through SP' parallel to $f'v'd_1'$, below VII.

72. Having found the perspectives of these vanishing points, the perspectives of the vanishing traces of all the planes in the object should be drawn as a test of the accuracy with which the vanishing points have been constructed. The roof planes in the house are lettered with the capital letters M, N, O, P, etc., on the diagram.

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The plane O contains the lines af , ad , and fd . Therefore, the vanishing trace (TO) of the plane must be a straight line passing through the three vanishing points, v^{af} , v^{ad} , and v^{fd} (§ 24 *d*). If all three of these vanishing points do not lie in a straight line, it shows some inaccuracy, either in draughting or in the method used in finding some of the vanishing points. The student should not be content until the accuracy of his work is proved by drawing the vanishing trace of each plane in the object through the vanishing points of all lines that lie in that plane.

The plane M contains the lines fd , gc , and dc . The last line belongs to the system ab , and hence its vanishing point is v^{ab} . The vanishing trace (TM) of the plane M must pass through v^{fd} , v^{gc} , and v^{ab} .

Similarly, the vanishing trace (TP) of the plane P must pass through v^{gc} , v^{bg} , and v^{ad} . TN must pass through v^{ab} , v^{af} , and v^{bg} . TQ must pass through v^{hk} and v^{ad} . TR must pass through v^{kl} and v^{ad} .

73. The vanishing trace of a vertical plane will always be a *vertical line* passing through the vanishing points of all lines which lie in the plane. Therefore, the vanishing trace of the vertical planes in the house that vanish towards the left will be represented by a vertical line (TS) passing through v^{ad} .

The vanishing trace of the vertical planes of the house that vanish towards the right will be represented by a vertical line (TT) passing through v^{ab} . As the vertical plane which forms the face of the porch belongs to this system, and as this plane also contains the lines hk and kl , TT will be found to pass through v^{hk} and v^{kl} as well as v^{ab} .

74. It will be noticed that the vanishing points for the lines mn and on have not been found. These vanishing points might have been found in a manner exactly similar to that in which the other vanishing points were found, or they may be determined now, directly from the vanishing traces already drawn, in the following manner:—

The line mn is seen to be the line of intersection of the two planes N and Q. Therefore (§ 24 *e*) v^{mn} must lie at the intersection of TN and TQ.

For a similar reason, v^{on} must lie at the intersection of TN

and TR. TN and TR do not intersect within the limits of the plate, but they are seen to converge as they pass to the left, and, if produced in that direction, would meet at the vanishing point for the line *on*.

75. Having found v^{ab} , v^{ad} , v^{bg} , and v^{fd} , TN could have been drawn through v^{ab} and v^{bg} ; and TO could have been drawn through v^{ad} and v^{fd} . As *qt* is the intersection of the two planes N and O, v^{qt} could have been found at the intersection of TN and TO without actually constructing this vanishing point.

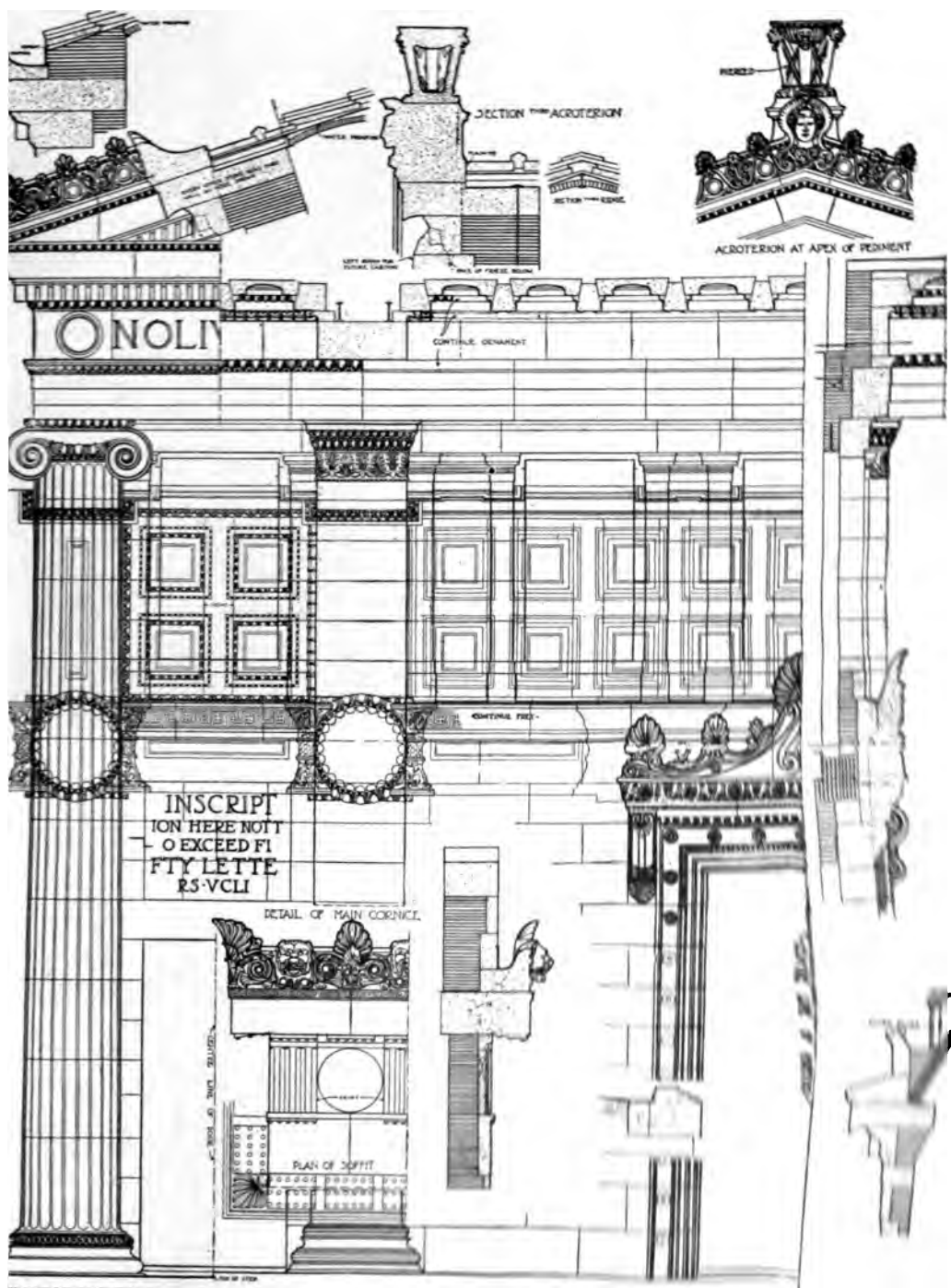
Similarly, v^{se} could have been determined by the intersection of TM and TP.

By an examination of the plate, the student will notice that the vanishing point for each line in the object is formed at the intersection of the vanishing traces of the two planes of which the line forms the intersection. Thus, the line *ad* forms the intersection between the plane O and the left hand vertical face of the house. v^{ad} is found at the intersection of TO and TS.

The line *fg*, which forms the ridge of the roof, is the intersection of the planes M and N. The vanishing point for *fg* is v^{ab} , and TM and TN will be found to intersect at v^{ab} . v^{hk} is found at the intersection of TQ and TT, v^{kl} is found at the intersection of TR and TT, etc.

It will be noticed also that the two lines *hk* and *kl* lie in the same vertical plane, and make the same angle with the horizontal, one vanishing upward, and one vanishing downward. Since both lines lie in the same vertical plane, both of their vanishing points will be found in the vertical line which represents the vanishing trace of that plane. Also, since both lines make equal angles with the horizontal, the vanishing point of the line vanishing upward will be found as far above VII as the vanishing point of the line vanishing downward is below VII.

In a similar way, the line *bg* vanishes upward, and the line *fl* vanishes downward; each making the same angle with the horizontal (as shown by the given plan and elevation). These two lines do not lie in the same plane, but may be said to lie in two imaginary vertical planes which are parallel to one another. Their vanishing points will be seen to lie in the same vertical line, v^{bg} being as far above VII as v^{fd} is below it.



NO SHADING BY PREFERENCE
SCALE ELEVATION IN TOURING
RES.

THREE-QUARTER-SCALE DETAIL OF THE CENTRAL PAVILION
CENTRAL PAVILION - PASTEL DRAWING - THE BROOKLYN
BROOKLYN - INSTITUTE -

1888

FROM HEAD OF THE ARCHITECT

SECTION OF A TYPICAL ARCHITECTURAL DRAWING, FROM TOP OF THE FIRST STORY ARCHITECTURAL DRAWING
Note how much information is crowded into a single sheet



As a general statement, it may be said that if two lines lie in the same or parallel vertical planes and make equal angles with the horizontal, one vanishing upward and the other vanishing downward, the vanishing points for both lines will be found vertically in line with one another, one as far above VH as the other is below it.

This principle is first of use in constructing the vanishing point diagram. Thus having found v^k , k' could be located by determining vertically by making it lie in a vertical plane with v^k , and as far below VH as k^k is above it.

VANISHING POINT DIAGRAM.

76. The somewhat symmetrical figure formed by the vanishing traces of all the planes in the object, together with all vanishing points, HPP, and the vertical and horizontal projections of the station point, is called the *Vanishing Point Diagram* of the object.

77. Having found the complete vanishing point diagram of the house, the perspective projection may be drawn. VH_1 may be chosen in accordance with the kind of a perspective projection it is desired to produce (§ 29). In order that all the roof lines may be visible, VH_1 has been chosen far below VH . The resulting perspective is a somewhat exaggerated bird's eye view.

The point e^p will be found on VH_1 , vertically under the point e in the diagram. $a^p e^p$ lies in the picture plane, and shows the true height of the vertical wall of the house. From a^p and e^p , the horizontal edges of the walls of the main house vanish to v^{ab} and v^{cd} .

The points d^p , b^p , m^p , and o^p are found on the upper horizontal edges of the main walls, vertically under the points where HPP is crossed by visual rays drawn through the points d , b , m , and o in the diagram. Vertical lines from d^p and b^p complete the visible vertical edges of the main house.

In a similar manner the perspective of the vertical walls of the porch is obtained.

Each roof line vanishes to its respective vanishing point. $a^p f^p$ vanishes at v^{af} . $f^p d^p$ vanishes at v^{fd} . These two lines inter-

sect in the point f^P . The ridge of the main house passes through f^P , vanishing at v^{ab} . $g^P c^P$ vanishes at v^{gc} , passing through the point c^P , which has already been determined by the intersection of the two upper rear horizontal edges of the main walls. $b^P g^P$ vanishes at v^{bg} , completing the perspective of the main roof.

In the porch, $h^P k^P$ vanishes at v^{hk} , passing through the point h^P , already determined by the vertical walls of the porch. $k^P l^P$ passes through l^P , and vanishes at v^{kl} . From k^P the ridge of the porch roof vanishes at v^{kd} . From m^P , a line vanishing at v^{mn} will intersect the ridge in the point n^P , and represent the intersection of the roof planes Q and N. The vanishing point for $o^P n^P$ falls outside the limits of the plate. $o^P m^P$ may be connected with a line which, if the drawing is accurate, will converge towards both TN and TR, and, if produced, would meet them at their intersection.

78. While constructing the vanishing point diagram of an object, the student should constantly keep in mind the general statements made in the note under § 69.

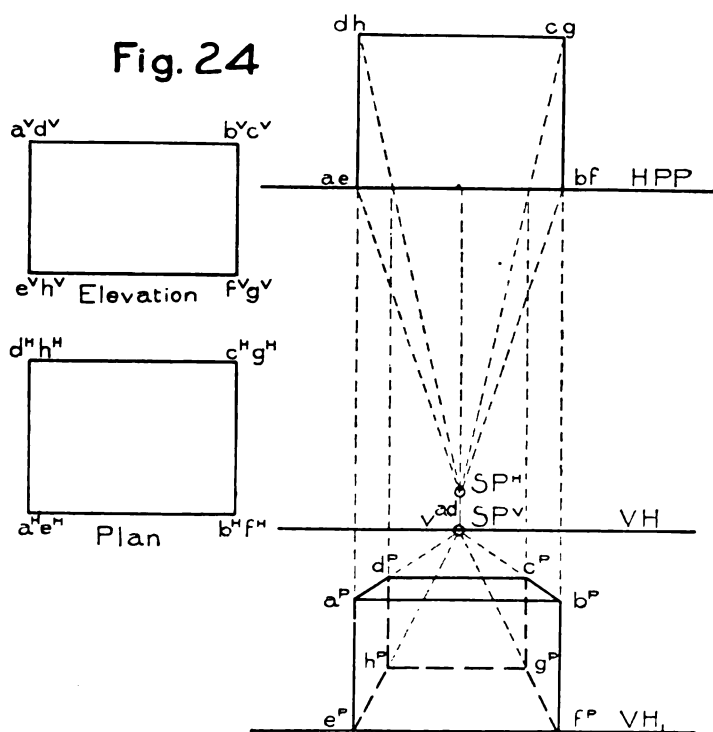
Plate IV. should now be solved.

PARALLEL OR ONE-POINT PERSPECTIVE.

79. When the diagram of an object is placed with one of its principal systems of horizontal lines parallel to the picture plane, it is said to be in **Parallel Perspective**. This is illustrated in Fig. 24, by the rectangular block there shown. One system of horizontal lines in the block being parallel to the picture plane, the other system of horizontal lines must be perpendicular to the picture plane. The vanishing point for the latter system will be coincident with SP^V (§ 52). The horizontal system that is parallel to the picture plane will have no vanishing point within finite limits (§ 54, with note; also last paragraph of note under § 69). The third system of lines in the object is a vertical one, and will have no vanishing point within finite limits (§ 54). Thus, of the three systems of lines that form the edges of the block, only one will have a vanishing point within finite limits. This fact has led to the term One-Point Perspective, which is often applied to an object in the position shown in Fig. 24. As will be seen, this

is only a special case of the problems already studied, and the construction of the perspective of an object in parallel perspective is usually simpler than when the diagram is turned at an angle with HPP.

80. The vertical face ($abfe$) of the block lies in the picture plane. It will thus show in its true size and shape (§ 24 *h*). The



points e^p and f^p will be found on VH_1 vertically below the points e and f in the diagram.

81. Both the edges $e^p a^p$ and $f^p b^p$ are lines of measures, and will show the true height of the block, as given by the elevation.

82. The two lines $a^p b^p$ and $e^p f^p$, since they are formed by the intersection of the bases of the block with the picture plane, will also be lines of measures (§ 55), and will show the true length of the block, as given by the plan and elevation.

83. The perspective of the front face of the block, which is

coincident with the picture plane, can be drawn immediately. From a^p , b^p , e^p , and f^p , the horizontal edges, which are perpendicular to the picture plane, will vanish at v^m (coincident with SP^v). The rear vertical edges of the block may be found in the usual manner.

84. The lines $a^p b^p$, $d^p c^p$, $e^p f^p$, and $h^p g^p$, which form the horizontal edges parallel to the picture plane, will all be drawn parallel to one another (§ 54, note); and since the lines in space which they represent are horizontal, $a^p b^p$, $d^p c^p$, $e^p f^p$, and $h^p g^p$ will all be horizontal (see last paragraph of note under § 69).

All of the principles that have been stated in connection with the other problems will apply equally well to an object in parallel perspective.

85. Interior views are often shown in parallel perspective. One wall of the interior is usually assumed coincident with the picture plane, and is not shown in the drawing. For illustration, the rectangular block in Fig. 24 may be considered to represent a hollow box, the interior of which is to be shown in perspective. Assume the face ($a^p b^p f^p e^p$) that lies in the picture plane to be removed. The resulting perspective projection would show the interior of the box. In making a parallel perspective of an interior, however, VH is usually drawn lower than is indicated in Fig. 24, in order to show the inside of the upper face, or ceiling, of the interior. With such an arrangement, three walls, the ceiling, and the floor of the interior, may all be shown in the perspective projection.

86. Fig. 25 shows an example of interior parallel perspective. The plan of the room is shown at the top of the plate. This has been placed so that it may be used for the diagram, and save the necessity of making a separate drawing. The elevation of the room is shown at the left of the plate, and for convenience it has been placed with its lower horizontal edge in line with VH_1 . In this position all vertical dimensions in the object may be carried by horizontal construction lines directly from the elevation to the vertical line of measures ($a^p c^p$ or $b^p f^p$) in the perspective projection.

87. The front face of the room ($a^p b^p f^p e^p$), which is coincident with the picture plane, may first be established. Each point

in the perspective of this front face will be found to lie vertically under the corresponding point in plan, and horizontally in line with the corresponding point in elevation. Thus, a^p is vertically under a^u , and horizontally in line with a^v .

All lines in the room which are perpendicular to the picture plane vanish at v^{ad} (coincident with SP^v).

Drawing visual rays from every point in the diagram, the corresponding points in the perspective projection will be vertically under the points where these visual rays intersect HPP. The construction of the walls of the room should give the student no difficulty.

88. In finding the perspective of the steps, the vertical heights should first be projected by horizontal construction lines from the elevation to the line of measures ($a^p c^p$), as indicated by the divisions between c^p and m . These divisions can then be carried along the left hand wall of the room by imaginary horizontal lines vanishing at v^{ad} . The perspective of the vertical edge where each step intersects the left hand wall may now be determined from the plan. Thus, the edge $s^p r^p$ of the first step is vertically below the intersection of HPP with a visual ray drawn through the point s^u in plan, and is between the two horizontal lines projected from the elevation that show the height of the lower step. The corresponding vertical edge of the second step will be projected from the plan in a similar manner, and will lie between the two horizontal lines projected from the elevation that show the height of the second step, etc.

From s^p the line which forms the intersection of the wall with the horizontal surface of the first step will vanish to v^{ad} , etc.

From r^p the intersection of the first step with the floor of the room will be a line belonging to the same system as $a^p b^p$, and will therefore show as a true horizontal line. The point t^p may be projected from the diagram by a visual ray, as usual. From t^p the vertical edge of the step may be drawn till it intersects a horizontal line through s^p , and so on, until the steps that rest against the side wall are determined.

89. The three upper steps in the flight rest against the rear wall. The three upper divisions on the line $c^p m$ may be carried along the left hand wall of the room, as indicated, till they inter-

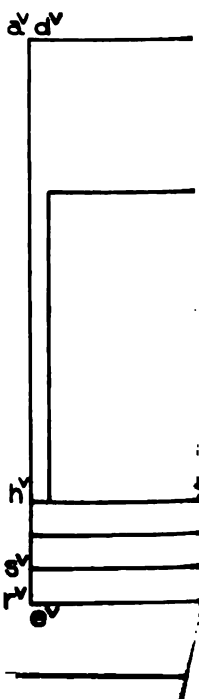
sect the rear vertical edge of the wall, represented by the line $d''h''$. From these intersections the lines may be carried along the rear wall of the room, showing the heights of the three upper steps where they rest against the rear wall.

The three upper divisions on the line $e''m$ have also been projected across to the line $f''b''$, and from this line carried by imaginary horizontal lines along the right hand wall of the room to the plane N, across the plane N to the plane O, and from the plane O to the plane M. Thus, for illustration, the upper division, representing the height of the upper step, has been carried from m to e ; from e to g along the right hand face of the wall; from g to j along the plane N; from j to k on the plane O, and from k to p'' on the plane M.

The point p'' is where the line which represents the height of the upper step meets a vertical dropped from the intersection of HPP with a visual ray through the point p'' in the diagram. p'' is one corner in the perspective of the upper step, the visible edges of the step being represented by a horizontal line, $p''k$, a line ($p''o''$) vanishing at v''^d , and a vertical line drawn from p'' between the two horizontal lines on the plane H, which represent the height of the upper step. The point o'' is at the intersection of the line drawn through p'' , vanishing through v''^d , with the horizontal line on the rear wall drawn through the point n , and representing the upper step where it rests against the rear wall.

The remaining steps may be found in a similar manner. The student should have no difficulty in following out the construction, which is all shown on the plate.

90. The position of the point t'' on the line $r''t''$ was determined by projecting in the usual manner from the diagram. The position of t'' might have been found in the following manner: In the figure the line $e''f''$ is a line of measures (§ 81), and divisions on this line will show in their true size. Thus, if we imagine a horizontal line to be drawn through t'' , parallel to the wall of the room, it will intersect $e''f''$ in the point u . Since $e''u$ is on a line of measures, it will show in its true length. Thus, t'' might have been determined by laying off $e''u$ equal to the distance $e''u_1$ taken from the plan, and then drawing through the point u a line van-



1000

1000

1000

1000

1000

ishing at v^{ad} . The intersection of this line with the horizontal line drawn through r^P will determine t^P .

In a similar manner the vertical edges of the steps, where they intersect the plane M, might have been found by laying off from u , on $e^P f^P$, the divisions uv and vw taken from the plan. These divisions could have been carried along the floor by horizontal lines parallel to the sides of the room (vanishing at v^{ad}), to the plane M, and then projected vertically upward on the plane M, as indicated in the figure.

Solve Plate V.

METHOD OF PERSPECTIVE PLAN.

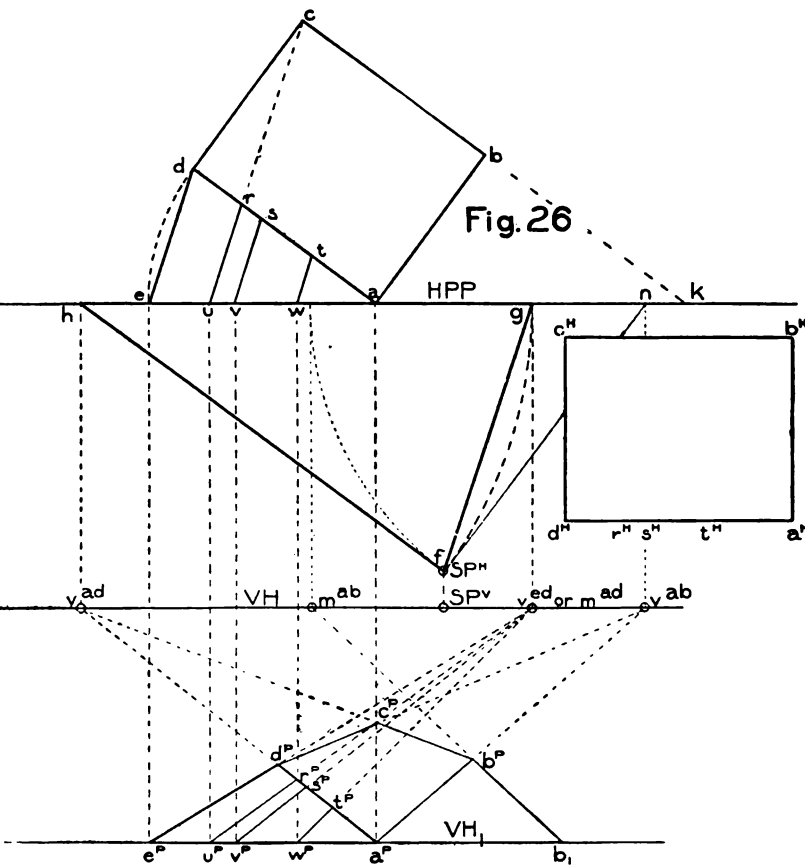
91. In the foregoing problems the perspective projection has been found from a diagram of the object. Another way of constructing a perspective projection is by the method of **Perspective Plan**. In this method no diagram is used, but a perspective plan of the object is first made, and from this perspective plan the perspective projection of the object is determined. The perspective plan is usually supposed to lie in an auxiliary horizontal plane below the plane of the ground. The principles upon which its construction is based will now be explained.

92. In Fig. 26, suppose the rectangle $a^H b^H c^H d^H$ to represent the horizontal projection of a rectangular card resting upon a horizontal plane. The diagram of the card is shown at the upper part of the figure. It will be used only to explain the construction of the perspective plan of the card.

First consider the line ad , which forms one side of the card. On HPP lay off from a , to the left, a distance (ae) equal to the length of the line ad . Connect the points e and d . ead is by construction an isosceles triangle lying in the plane of the card, with one of its equal sides (ae) in the picture plane. Now, if this triangle be put into perspective, the side ad , being behind the picture plane, will appear shorter than it really is; while the side ae , which lies in the picture plane, will show in its true length.

Let VH_1 be the vertical trace of the plane on which the card and triangle are supposed to rest. The position of the station point is shown by its two projections SP^H and SP^V . The vanish-

ing point for the line ad will be found at v^{ad} in the usual manner. In a similar way, the vanishing point for the line ed , which forms the base of the isosceles triangle, will be found at v^{ed} , as indicated. a^p will be found on VH_1 vertically under the point a , which forms the apex of the isosceles triangle ead . The line $a^p d^p$ will vanish at v^{ad} . The point e^p will be found vertically



below the point e . $e^p d^p$ will vanish at v^{ed} , and determine by its intersection with $a^p d^p$ the length of that line. $e^p a^p d^p$ is the perspective of the isosceles triangle ead .

If the line ad in the diagram is divided in any manner by the points t , s , and r , the perspectives of these points may be found on the line $a^p d^p$ in the following way. If lines are drawn

through the points t , s , and r in the diagram parallel to the base de of the isosceles triangle (ead), these lines will divide the line ae in a manner exactly similar to that in which the line ad is divided. Thus, aw will equal at , wv will equal ts , etc. Now, in the perspective projection of the isosceles triangle, $a^p e^p$ lies in the picture plane. It will show in its true length, and all divisions on it will show in their true size. Thus, on $a^p e^p$ lay off $a^p w^p$, $w^p v^p$, and $v^p u^p$ equal to the corresponding distances at , ts , and sr , given in the diagram. Lines drawn through the points w^p , v^p , and u^p , vanishing at v^{ed} , will be the perspective of the lines wt , ts , and ur in the isosceles triangle, and will determine the positions of t^p , s^p , and r^p , by their intersections with $a^p d^p$.

93. It will be seen that after having found v^{ad} and v^{ed} , the perspective of the isosceles triangle can be found without any reference to the diagram. Assuming the position of a^p at any desired point on VH_1 , the divisions a^p , w^p , v^p , u^p , e^p may be laid off from a^p directly, making them equal to the corresponding divisions a^H , t^H , s^H , r^H , d^H , given in the plan of the card. A line through a^p vanishing at v^{ad} will represent the perspective side of the isosceles triangle. The length of this side will be determined by a line drawn through e^p , vanishing at v^{ed} . The positions of t^p , s^p , and r^p may be determined by lines drawn through w^p , v^p , and u^p , vanishing at v^{ed} .

94. It will be seen that the lines drawn to v^{ed} serve to measure the perspective distances $a^p t^p$, $t^p s^p$, $s^p r^p$, and $r^p d^p$, on the line $a^p d^p$, from the true lengths of these distances as laid off on the line $a^p e^p$. Hence the lines vanishing at v^{ed} are called **Measure Lines** for the line $a^p d^p$, and the vanishing point v^{ed} is called a **Measure Point** for $a^p d^p$.

95. Every line in perspective has a measure point, which may be found by constructing an isosceles triangle on the line in a manner similar to that just explained.

NOTE. — The vanishing point for the base of the isosceles triangle always becomes the measure point for the side of the isosceles triangle which does not lie in HPP .

96. All lines belonging to the same system will have the same measure point. Thus, if the line bc , which is parallel to ad , be continued to meet HPP , and an isosceles triangle (cku) con

structed on it, as indicated by the dotted lines in the figure, the base (uc) of this isosceles triangle will be parallel to de , and its vanishing point will be coincident with v^{de} .

97. There is a constant relation between the vanishing point of a system of lines and the measure point for that system. Therefore, if the vanishing point of a system of lines is known, its measure point may be found without reference to a diagram, as will be explained.

In constructing the vanishing points v^{ad} and v^{ed} , fh was drawn parallel to ad , fg was drawn parallel to ed , and since hg is coincident with HPP, the two triangles ead and fhy must be similar. As ae was made equal to ad in the small triangle, hf must be equal to hg in the large triangle; and consequently v^{ed} , which is as far from v^{ad} as g is from h , must be as far from v^{ad} as the point f is from the point h .

If the student will refer back to Figs. 8, 9, and 9a, he will see that the point h bears a similar relation in Fig. 26 to that of the point m^H in Figs. 8, 9, and 9a, and that the point h in Fig. 26 is really the horizontal projection of the vanishing point v^{ad} . (See also § 32.) Therefore, as v^{ed} is as far from v^{ad} as the point h is from the point f , we may make the following statement, which will hold for all systems of horizontal lines.

98. *The measure point for any system of horizontal lines will be found on VII as far from the vanishing point of the system as the horizontal projection of that vanishing point is distant from the horizontal projection of the station point.*

NOTE. — In accordance with the construction shown in Fig. 26, SP^V will always lie between the vanishing point of a system and its measure point.

99. The measure point of any system of lines is usually denoted by a small letter m with an index corresponding to its related vanishing point. Thus, m^{ab} signifies the measure point for the system of lines vanishing at v^{ab} .

100. The vanishing point for ab in Fig. 26 has been found at v^{ab} . The point n , in HPP, is the horizontal projection of this vanishing point. The measure point (m^{ab}) for all lines vanishing at v^{ab} will be found on VII, at a distance from v^{ab} equal to the distance from n to SP^H (98). In accordance with this statement,

m^{ab} has been found by drawing an arc with n as center, and with a radius equal to the distance from n to SP^H , and dropping from the intersection of this arc with HPP a vertical line. m^{ab} is found at the intersection of this vertical line with VH .

101. The perspective of ab has been drawn from a^P , vanishing at v^{ab} . $a^P b_1$ on VH_1 is made equal to the length of $a^H b^H$ given in the plan of the card. A measure line through b_1 , vanishing at m^{ab} , will determine the length of $a^P b^P$. A line from b^P vanishing at v^{ad} , and one from d^P vanishing at v^{ab} , will intersect at c^P , completing the perspective plan of the card.

102. Even the vanishing points (v^{ab} and v^{ad}) for the sides of the card may be found without drawing a diagram. Since fn is drawn parallel to ab , it makes the same angle with HPP that ab makes. Similarly, since fh is drawn parallel to ad , it makes the same angle with HPP that ad makes. The angle between fn and fh must show the true angle made by the two lines ab and ad in the diagram. Therefore, having assumed SP^H , we have simply to draw two lines through SP^H , making with HPP the respective angles that the two sides of the cards are to make with the picture plane, care being taken that the angle these two lines make with one another shall equal the angle shown between the two sides of the card in the given plan. Thus, in Fig. 27, the two projections of the station point have first been assumed. Then through SP^H , two lines (fn and fh) have been drawn, making respectively, with HPP, the angles (H° and N°) which it is desired the sides of the card shall make with the picture plane, care being taken to make the angle between fn and fh equal to a right angle, since the card shown in the given plan is rectangular.

Verticals dropped to VH from the points n and h will determine v^{ab} and v^{ad} . Having found v^{ab} and v^{ad} , m^{ab} and m^{ad} should next be determined, as explained in § 98. VH_1 should now be assumed, and a^P chosen at any point on this line. It is well not to assume a^P very far to the right or left of an imaginary vertical line through SP^V .

From a^P the sides of the card will vanish at v^{ab} and v^{ad} respectively. Measure off from a^P on VH_1 , to the right, a distance ($a^P b_1$) equal to the length of the side $a^H b^H$ shown in the given plan. A measure line through b_1 , vanishing at m^{ab} , will deter-

mine the length of $a^p b^p$. Measure off from a^p on VH_1 , to the left, a distance ($a^p d_1$) equal to the length of the side $a^h d^h$ shown in the given plan. A measure line through d_1 vanishing at m^{ad} , will determine the length of $a^p d^p$.

From b^p and d^p , the remaining sides of the card vanish to v^{ad} and v^{ab} respectively, determining by their intersection the point c^p .

The line $a^h d^h$ in plan is divided by points t^h , s^h , and r^h . To divide the perspective ($a^p d^p$) of this line in a similar manner, lay off on VH_1 from a^p , to the left, the divisions t_1 , s_1 , and r_1 , as taken from the given plan. Measure lines through t_1 , s_1 , and r_1 , vanishing at m^{ad} , will intersect $a^p d^p$, and determine t^p , s^p , and r^p .

103. As has already been stated, the true length of any line is always measured on VH_1 , and from the true length, the length of the perspective projection of the line is determined by measure lines vanishing at the measure point for the line whose perspective is being determined. Care must be taken to measure off the true length of the line in the proper direction. The general rule for doing this is as follows: —

If the measure point of any line is at the *right* of SP^v , the true length of the line will be laid off on VH_1 in such a manner that measurements for the *more distant* points in the line will be to the *left* of the measurements for the *nearer* points.

Thus, m^{ad} is at the *right* of SP^v . The point d^p is more distant than the point t^p . Therefore, the measurement (d_1) for the point d^p will be to the *left* of the measurement for the point t^p . In other words, since m^{ad} is to the *right* of SP^v , d_1 , which represents a point more distant than t_1 , must be to the *left* of t_1 , the distance between t_1 and d_1 being equal to the true length of $t^p d^p$, as shown by $t^h d^h$ in the given plan.

On the other hand, if the measure point for any system of lines is to the *left* of SP^v , the true measurements for any line of the system should be laid off on VH_1 in such a manner that measurements for more *distant points* on the line are to the *right* of measurements for the *nearer* points of the line.

Thus, m^{ab} is to the *left* of SP^V . The point b^P is *more distant* than the point a^P . Therefore, b_1 , which shows the true measurement for the point b^P , must be laid off to the *right* of a^P .

104. It sometimes happens that a line extends in front of the picture plane, as has already been seen in the lines of the nearest corner of the porch in Fig. 22. It may be desired to extend the line $a^P d^P$ in Fig. 27, in front of the picture plane, to the point y^P , as indicated in the perspective projection. In this case, the point a^P being *more distant* than the point y^P , and m^{ad} being to the *right* of SP^V , the true measurement of $a^P y^P$ must be laid off on VH_1 in such a manner that the measurement for a^P will be to the *left* of the measurement for y^P . In other words, y_1 must be on VH_1 to the right of a^P , the distance $a^P y_1$ showing the true length of $a^P y^P$.

NOTE. — The true length of any line which extends in front of the picture plane will be *shorter* than the perspective of the line.

105. Having determined the perspective of any line, as $d^P c^P$, its true length may be determined by drawing measure lines through d^P and c^P . The distance intercepted on VH_1 by these measure lines will show the true length of the line. Thus, $d^P c^P$ vanishes at m^{ab} . Its measure point must therefore be m^{ab} . Two lines drawn from m^{ab} , and passing through c^P and d^P respectively, will intersect VH_1 in the points c_1 and d_2 . The distance between c_1 and d_2 is the true length of $c^P d^P$. This distance will be found equal to $a^P b_1$, which is the true measure for the opposite and equal side ($a^P b^P$) of the rectangle.

In a similar manner, the true length of $b^P c^P$ may be found by drawing measure lines from m^{ad} through b^P and c^P respectively. $b_2 c_2$ will show the true length of $c^P b^P$, and should be equal to $a^P d_1$, which is the true length of the opposite and equal side ($a^P d^P$) of the rectangle.

106. The perspective (w^P) of a point on one of the rear edges of the card may be determined in either of the following ways: —

1st. From b_2 , which is the intersection with VH_1 of the measure line through b^P , lay off on VH_1 , to the left (§ 103), the distance $b_2 w_2$ equal to the $b^P w^P$ taken from the given plan. A

measure line through w_2 , vanishing at m^{ad} , will intersect $c^P b^P$ at the point w^P .

2d. In the given plan draw a line through w^H , parallel to $a^H b^H$, intersecting $a^H d^H$ in the point w_4 . On VH_1 make $a^P w_1$ equal to $a^H w_4$, as given in the plan. A measure line through w_1 , vanishing at m^{ad} , will determine w_3 on $a^P d^P$. From w_3 , a line parallel to $a^P b^P$ (vanishing at v^{ab}) will determine, by its intersection with $b^P c^P$, the position of w^P .

107. In making a perspective by the method of perspective plan, it is generally customary to assume VH and HPP coincident. That is to say, the coordinate planes are supposed to be in the position shown in Fig. 9, instead of being drawn apart as indicated in Fig. 9a. This arrangement simplifies the construction somewhat.

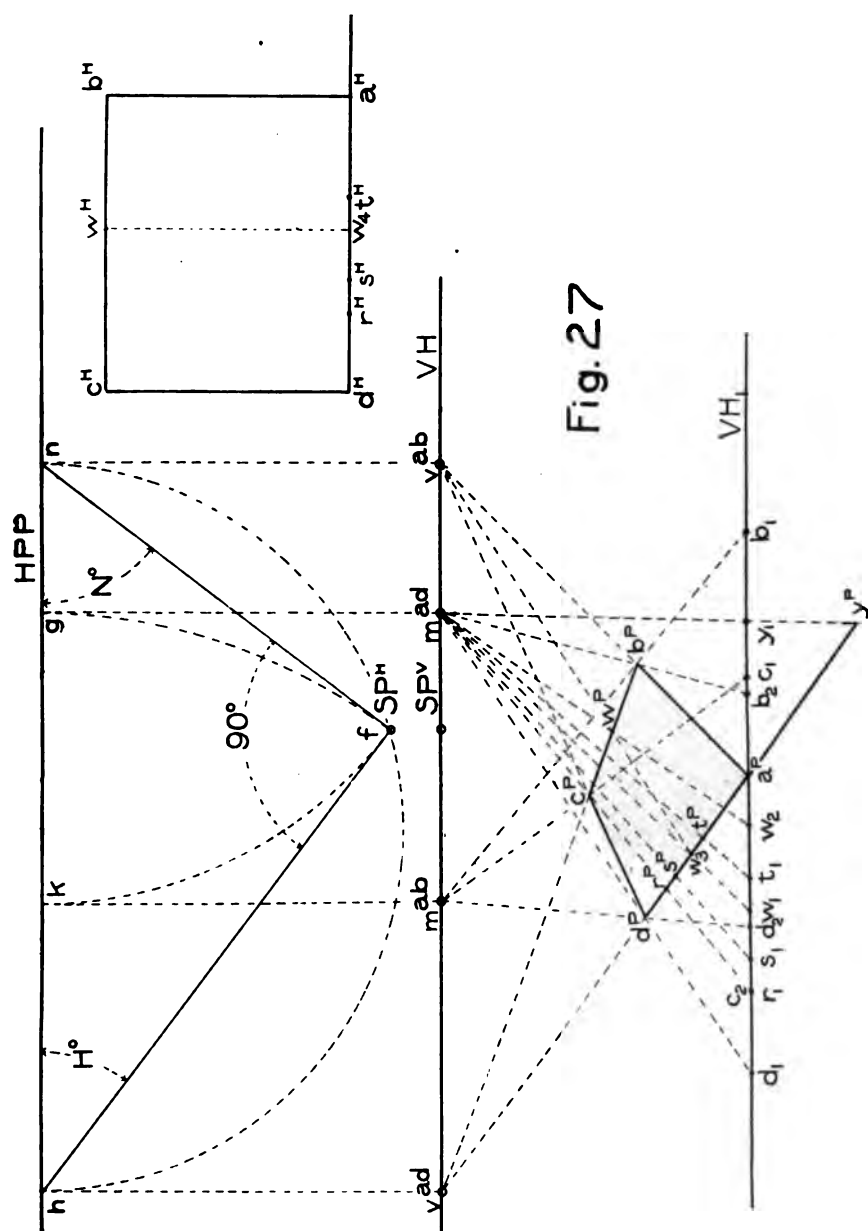
This is illustrated in Fig. 28, which shows a complete problem in the method of perspective plan. Compare this figure with Fig. 27, supposing that, in Fig. 27, HPP with all its related horizontal projections could be moved downward, until it just coincides with VH. The point n would coincide with v^{ab} , h with v^{ad} , and the arrangement would be similar to that shown in Fig. 28. All the principles involved in the construction of the measures, points, etc., would remain unchanged.

108. The vanishing points in Fig. 28 have first been assumed, as indicated at v^{ab} and v^{ad} . As the plan of the object is rectangular, SP^H may be assumed at any point on a semicircle constructed with $v^{ab}v^{ad}$ as diameter. By assuming SP^H in this manner, lines drawn from it to v^{ab} and v^{ad} respectively must be at right angles to one another, since any angle that is just contained in a semicircle must be a right angle. These lines show by the angles they make with HPP, the angles that the vertical walls of the object in perspective projection will make with the picture plane (§102).

109. m^{ad} and m^{ab} have been found, as explained in §97, in accordance with the rule given in §98.

VH_2 should next be assumed at some distance below VH, to represent the vertical trace of the horizontal plane on which the perspective plan is to be made (§91).

The position of a^P (on VH_2) may now be assumed, and the



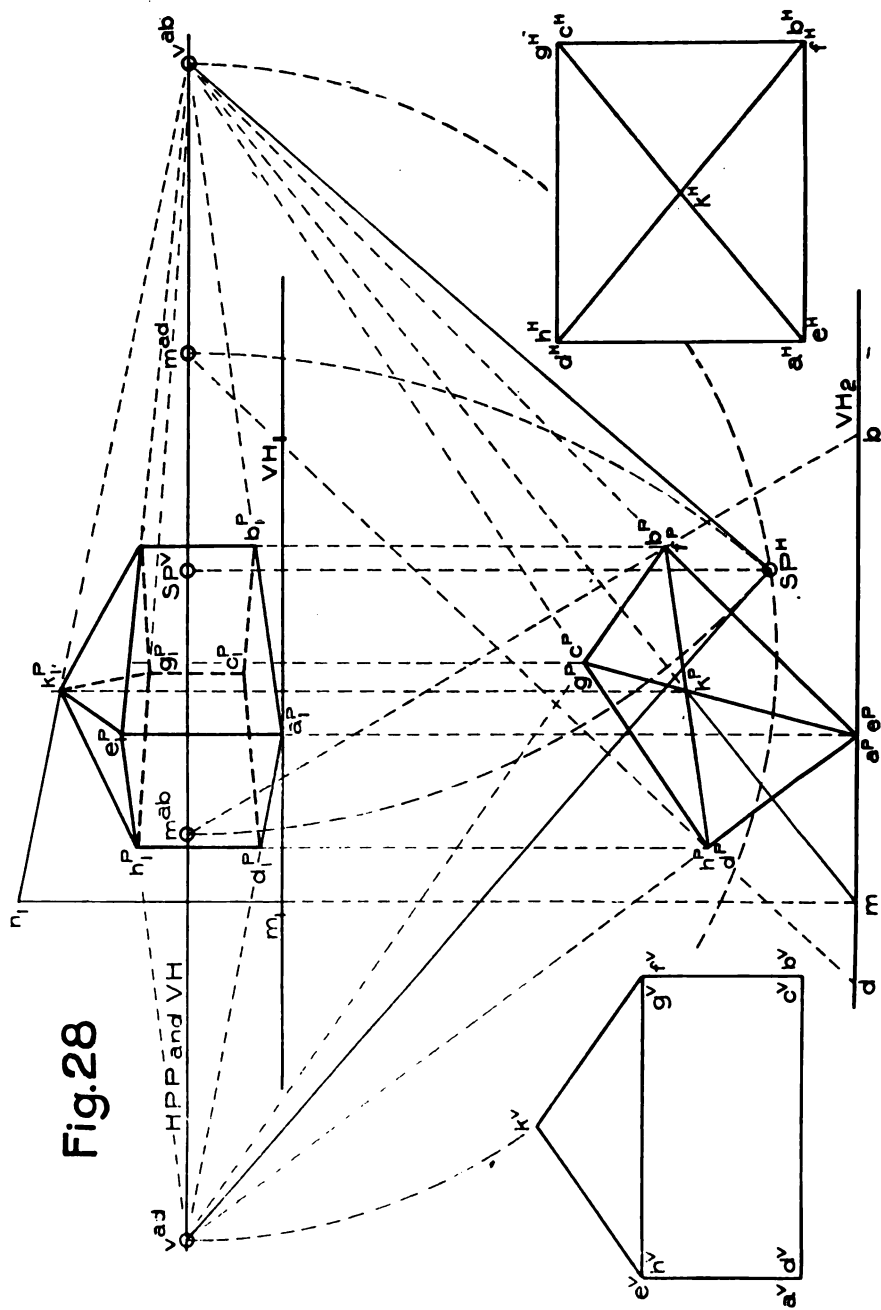
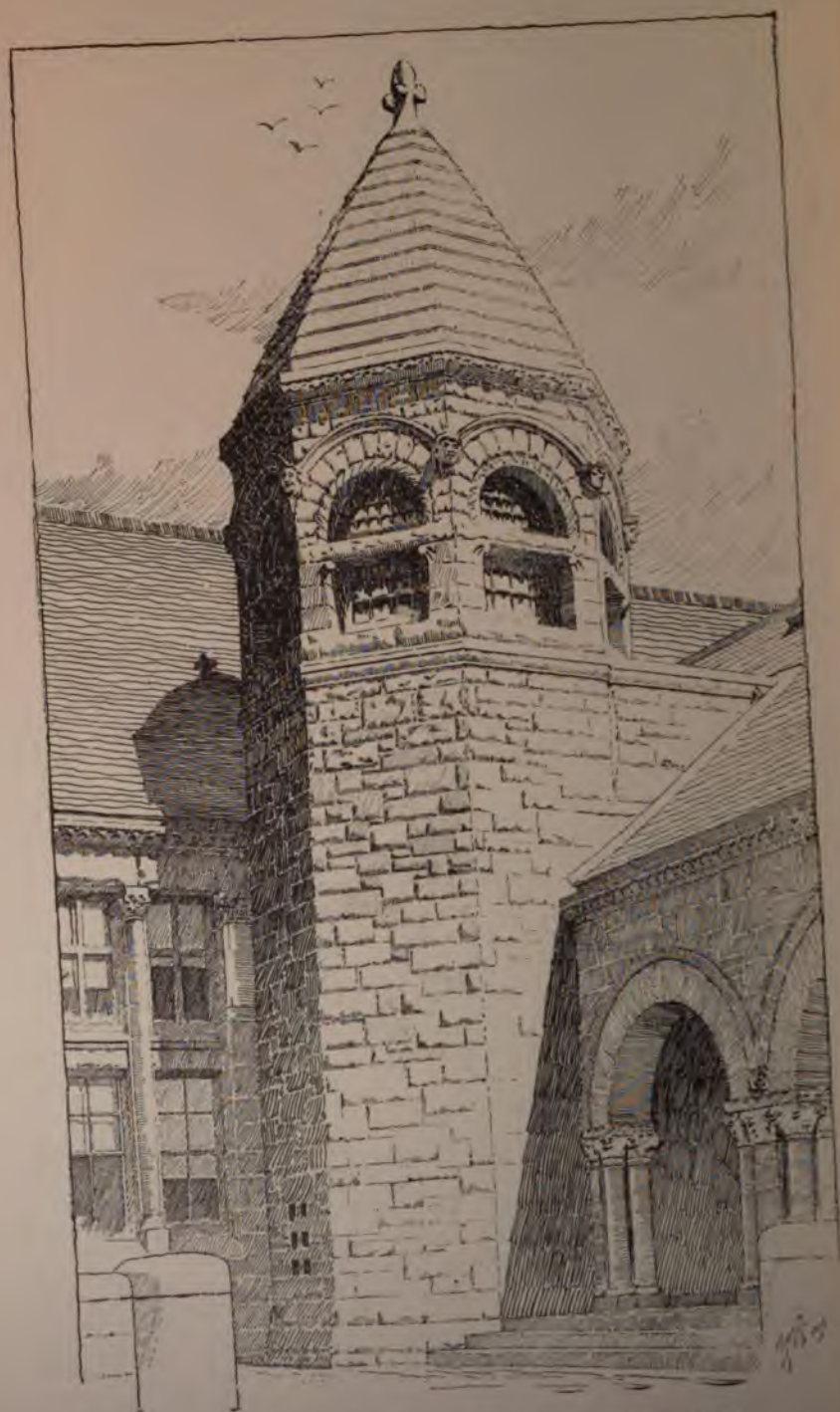


Fig.28



TOWER CONVERSE MEMORIAL LIBRARY, MALDEN, MASS.
H. H. Richardson, Architect.
Note treatment of shadows in a perspective drawing.

perspective plan of the object constructed from the given plan, exactly as was done in the case of the rectangular card in Fig. 27.

110. Having constructed the complete perspective plan, every point in the perspective projection of the object will be found *vertically* above the corresponding point in the perspective plan.

VH_1 is the vertical trace of the plane on which the perspective projection is supposed to rest. a_1^P is found on VH_1 vertically over a^P in the perspective plan. $a_1^P e_1^P$ is a vertical line of measures for the object, and shows the true height given by the elevation.

To find the height of the apex (k_1^P) of the roof, imagine a horizontal line parallel to the line ab to pass through the apex, and to be extended till it intersects the picture plane. A line drawn through k^P , vanishing at v^{ab} , will represent the perspective plan of this line, and will intersect VH_2 in the point m , which is the perspective plan of the point where the horizontal line through the apex intersects the picture plane. The vertical distance $n_1 m$, laid off from VH_1 , will show the true height of the point k above the ground. k_1^P will be found vertically above k^P , and on the line through n_1 vanishing at v^{ab} . The student should find no difficulty in following the construction for the remainder of the figure.

111. Fig. 29 illustrates another example of a similar nature to that in Fig. 28. The student should follow carefully through the construction of each point and line in the perspective plan and in the perspective projection. The problem offers no especial difficulty.

Plate VI. should now be solved.

CURVES.

112. Perspective is essentially a science of straight lines. If curved lines occur in a problem, the simplest way to find their perspective is to refer the curves to straight lines.

If the curve is of simple, regular form, such as a circle or an ellipse, it may be enclosed in a rectangle. The perspective of the

enclosing rectangle may then be found. A curve inscribed within this perspective rectangle will be the perspective of the given curve.

Fig. 30 shows a circle inscribed in a square. The points of intersection of the diameters with the sides of the square give the four points of tangency between the square and circle. The sides of the square give the directions of the circle at these points. Additional points on the circle may be established by drawing the diagonals of the square, and through the points m'' , k'' , n'' , and h'' drawing construction lines parallel to the sides of the square, as indicated in the figure.

Fig. 30

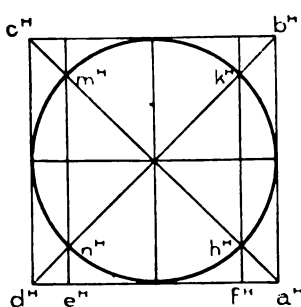
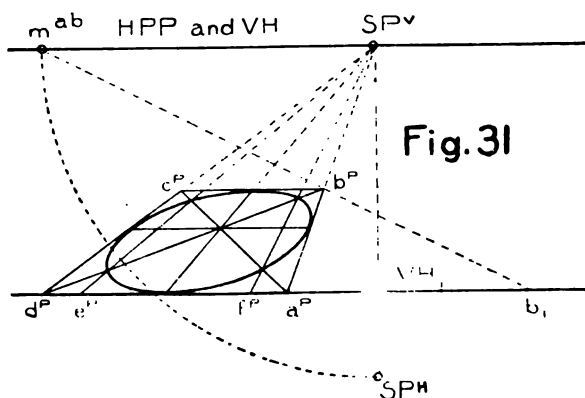
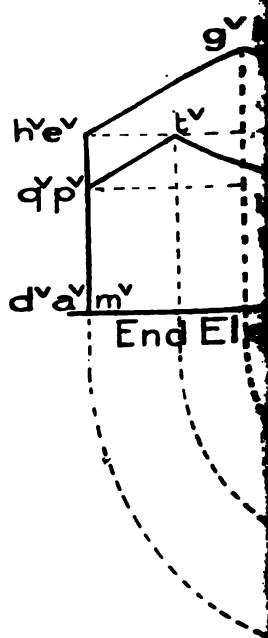


Fig. 31 shows the square, which is supposed to lie in a horizontal plane, in parallel perspective. One side of the square ($a^p d^p$) lies in the picture plane, and will show in its true size. The vanishing point for the sides perpendicular to the picture plane will coincide with SP^v (§ 52, note). The measure point for these sides has been found at m^{ab} , in accordance with



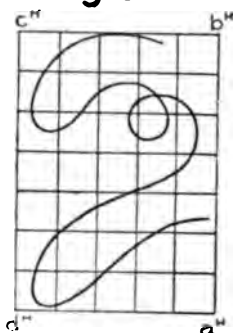
principles already explained. $a^p b_1$ is laid off on VH_1 to the right of the point a^p , equal to the true length of the side of the square. A measure line through b_1 , vanishing at m^{ab} , will determine the position of the point b^p . $b^p c^p$ will be parallel to $a^p d^p$ (§ 54, note).



The diagonals of the square may be drawn. Their intersection will determine the perspective center of the square. The diameters will pass through this perspective center, one vanishing at SP^V , and the other being parallel to $a^p d^p$ (§ 54, note).

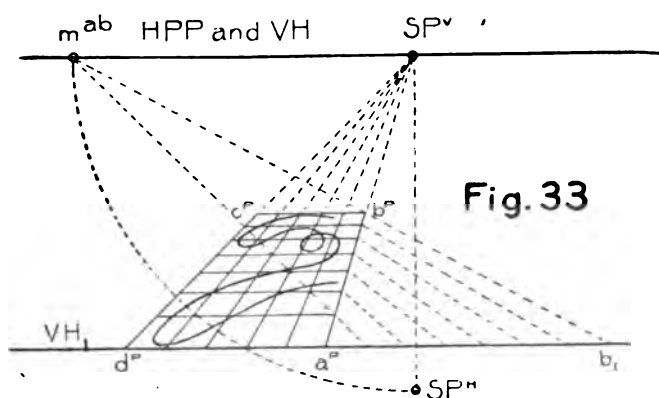
The divisions $d^p e^p$ and $a^p f^p$ will show in their true size. Lines through e^p and f^p , vanishing at SP^V , will intersect the diagonals of the square, giving four points on the perspective of the circle. Four other points on the perspective of the circle will be determined by the intersections of the diameter with the sides of the square. The perspective of the curve can be drawn as indicated.

Fig. 32



113. If the curve is of very irregular form, such as that shown in Fig. 32, it can be enclosed in a rectangle, and the rectangle divided by lines, drawn parallel to its sides, into smaller rectangles, as indicated in the figure.

The perspective of the rectangle with its dividing lines may then be found, and the perspective of the curve drawn in free



hand. This is shown in Fig. 33. If very great accuracy is required, the perspectives of the exact points where the curve crosses the dividing lines of the rectangle may be found.

APPARENT DISTORTION.

114. There seems to exist in the minds of some beginners in the study of perspective, the idea that the drawing of an object made in accordance with geometrical rules may differ essentially from the appearance of the object in nature. Such an idea is erroneous, however. The only difference between the appearance of a view in nature and its correctly constructed perspective projection is that the view in nature may be looked at *from any point*, while its perspective representation shows the view as seen from one particular point, and from that point only.

For every new position that the observer takes, he will see a new view of the object in space, his eye always being at the apex of the cone of visual rays that projects the view he sees (see Fig. 1). In looking at an object in space, the observer may change his position as often as he likes, and will see a new view of the object for every new position that he takes.

115. This is not true of the perspective projection of the object, however. Before making a perspective drawing, the position of the observer's eye, or station point, must be decided upon, and the resulting perspective projection will represent the object as seen from this point, and from this point only. The observer, when looking at the drawing, in order that it may correctly represent to him the object in space, must place his eye exactly at the assumed position of the station point. If the eye is not placed exactly at the station point, the drawing will not appear absolutely correct, and under some conditions will appear much distorted or exaggerated.

116. Just here lies the defect in the science of perspective. It is the assumption that the observer has but one eye. Practically, of course, this is seldom the case. A drawing is generally seen with two eyes, and the casual observer never thinks of placing his eye in the proper position. Even were he inclined to do so, it would generally be beyond his power, as the position of the station point is seldom shown on the finished drawing.

117. As an illustration of apparent distortion, consider the perspective projection shown in Fig. 23. In order that the perspectives of the vanishing points might fall within the rather

narrow limits of the plate, the station point in the figure has been assumed very close to the picture plane, the distance from HPP to SP^H showing the assumed distance from the paper at which the observer should place his eye in order to obtain a correct view of the perspective projection. This distance is so short it is most improbable that the observer will ordinarily place his eye in the proper position when viewing the drawing. Consequently the perspective projection appears more or less unnatural or distorted. But, for the sake of experiment, if the student will cut a small, round hole, one quarter of an inch in diameter, from a piece of cardboard, place it directly in front of SP^V and at a distance from the paper equal to the distance of SP^H from HPP, and if he will then look at the drawing through the hole in the cardboard, closing the eye he is not using, he will find that the unpleasant appearance of the perspective projection disappears.

It will thus be seen that unless the observer's eye is in the proper position while viewing a drawing, the perspective projection may give a very unsatisfactory representation of the object in space.

118. If the observer's eye is not very far removed from the correct position, the apparent distortion will not be great, and in the majority of cases will be unnoticeable. In assuming the position for the station point, care should be taken to choose such a position that the observer will naturally place his eyes there when viewing the drawing.

119. As a person naturally holds any object at which he is looking directly in front of his eyes, the first thought in assuming the station point should be to place it so that it will come very nearly in the center of the perspective projection.

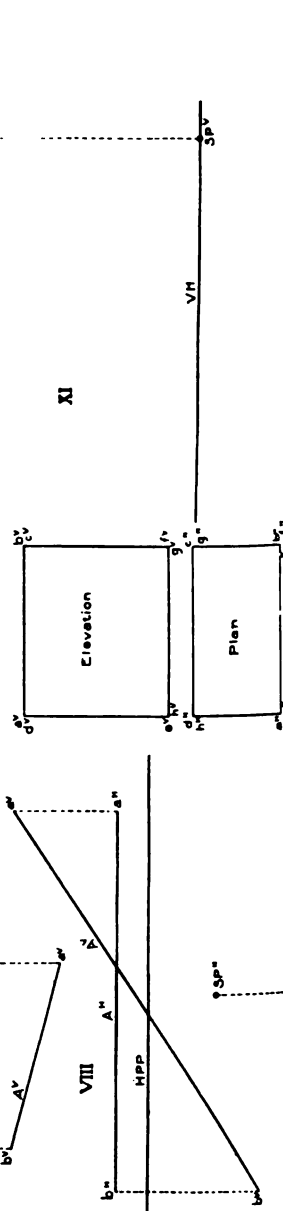
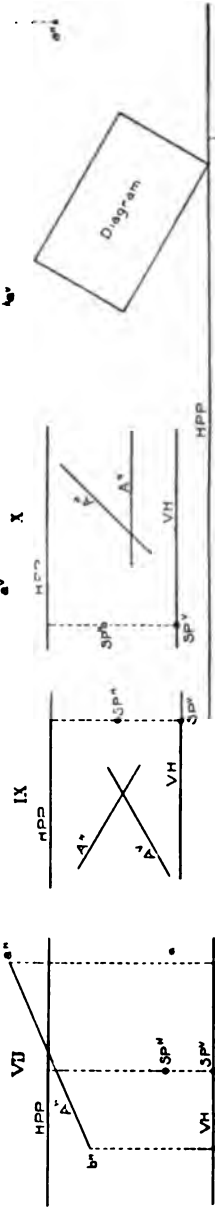
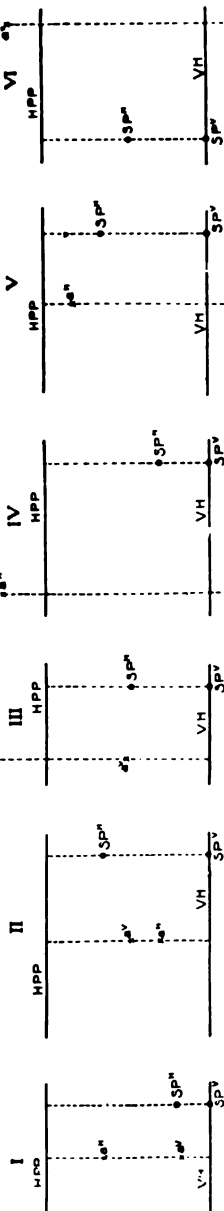
120. Furthermore, the normal eye sees an object most distinctly when about ten inches away. As one will seldom place a drawing nearer to his eye than the distance of distinct vision, a good general rule is to make the *minimum* distance between the station point and the picture plane about ten inches. For a small drawing, ten inches will be about right; but, as the drawing increases in size, the observer naturally holds it farther and farther from him, in order to embrace the whole without having to turn his eye too far to the right or left.

121. Sometimes a general rule is given to make the distance of the station point equal to the altitude of an equilateral triangle, having the extreme dimensions of the drawing for its base, and the station point for its apex.*

122. The apparent distortion is always greater when the assumed position of the observer's eye is too near than when it is too far away. In the former case, objects do not seem to diminish sufficiently in size as they recede from the eye. On the other hand, if the observer's eye is between the assumed position of station point and the picture plane, the effect is to make the objects diminish in size somewhat too rapidly as they recede from the eye. This effect is not so easily appreciated nor so disagreeable as the former. Therefore it is better to choose the position of the station point too far away, rather than too near.

123. Finally, the apparent distortion is more noticeable in curved than in straight lines, and becomes more and more disagreeable as the curve approaches the edge of the drawing. Thus, if curved lines occur, great pains should be taken in choosing the station point: and, if possible, such a view of the object should be shown that the curves will fall near the center of the perspective.

124. The student should realize that the so-called distortion in a perspective projection is only an apparent condition. If the eye of the observer is placed exactly at the position assumed for it when making the drawing, the perspective projection will exactly represent to him the corresponding view of the object in space.



PERSPECTIVE DRAWING.

Data to be used by student in solving plates. Leave all necessary construction lines. Letter all points, vanishing points, lines, etc., as found, in accordance with the notation given in the Instruction Paper.

PLATE I.

PROBLEMS I., II., III., IV., V., and VI. Find the perspective of the point *a*. Also in each problem locate the positions of the point *a*, and of the station point, as follow : —

" { — inches { behind
 or
 in front } of picture plane.
" { — inches { above
 or
 below } the plane of the horizon.

Station point — inches in front of the picture plane.

PROBLEMS VII. and VIII. Find the perspective of the line A.

PROBLEMS IX. and X. Find the perspective of the vanishing point of the system of lines parallel to the given line A.

PROBLEM XI. Find from the given plan and elevation the perspective projection of the rectangular block.

The view to be shown is indicated by the diagram. The station point is to be $3\frac{3}{4}$ inches in front of the picture plane. The position of SPV is given. The perspective projection is to rest upon a horizontal plane 2 inches below the level of the eye. Invisible lines in the perspective projection should be dotted.

PLATE II.

PROBLEM XII. To find the perspective of a cube the sides of which are $1\frac{3}{4}$ inches long, resting on a horizontal plane 1 inch below the observer's eye.

The nearest edge of the cube is about $1\frac{1}{8}$ inches behind the picture plane, as shown by the relation between the given diagram and HPP. The station point is to be $3\frac{3}{4}$ inches in front of the picture plane. The position of SP^V is given. Invisible edges of the cube should be dotted in the perspective projection.

PROBLEM XIII. To find the perspective of a cube similar to that in the last problem.

The position of the cube is such that it intersects the picture plane as indicated by the relation between the given diagram and HPP. The cube is supposed to rest on the horizontal plane represented by VII₁. The station point is to be $3\frac{3}{4}$ inches in front of the picture plane. The position of SP^V is given. Invisible edges should be dotted in the perspective projection.

PROBLEM XIV. Block pierced by a rectangular hole.

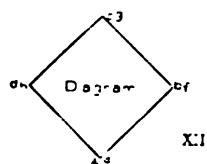
The plan and elevation given in the figure represent a rectangular block pierced by a rectangular hole which runs horizontally through the block from face to face, as indicated. The diagram, HPP, and the position of SP^V are given. The block is to rest on a horizontal plane $2\frac{5}{8}$ inches below the observer's eye. The observer's eye is to be $6\frac{1}{2}$ inches in front of the picture plane. Find the perspective projection of the block and of the rectangular hole. All invisible lines in the perspective projection should be dotted.

PLATE III.

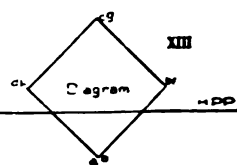
PROBLEM XV. Find the perspective projection of the house shown in plan, side and end elevations.

The diagram, HPP, and the projections of the station point are given. The house is supposed to rest on a horizontal plane $1\frac{3}{16}$ inch below the observer's eye. Invisible lines in this perspective projection need not be shown except as they may be needed for construction. All necessary construction lines should be shown; but the points in the perspective projection need not be lettered, except a^P , b^P , c^P , and d^P .

PLATE II



HDD



VM

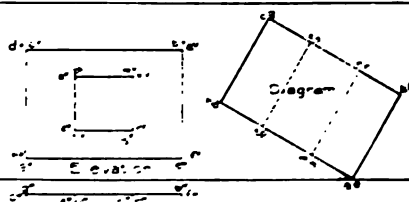
CP

VM

CP

VM

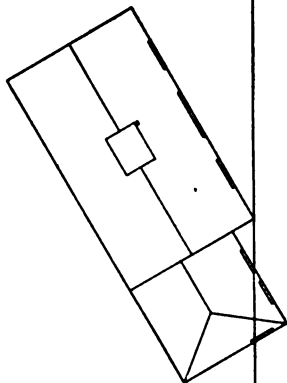
XIV



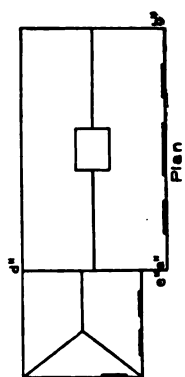
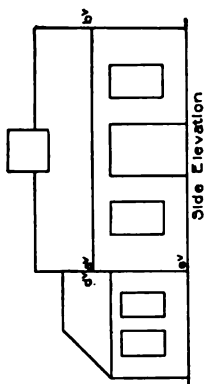
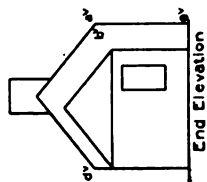
Diagram

PLATE II

XV



HPP



NAME

DATE

PLATE IV.

PROBLEM XVI.

The plate shows the plan, front, and side elevations of a house. In order to assist the student in understanding these drawings, an oblique projection (at one-half scale) is given, with the visible lines and planes lettered to agree with those in the plan and elevations.

The problem is, first, to find a complete Vanishing Point Diagram (§ 75) for the house in the position indicated by the given diagram; second, to draw the perspective projection of the house, resting on a horizontal plane six inches below the level of the observer's eye. The projections of the station point are given.

There will be, including the vertical system, eleven systems of lines and eight systems of planes in the vanishing point diagram.

NOTE. — The lines of these systems can most easily be identified by first finding their horizontal projections on the plan.

In finding the vanishing points for the different systems, the student should proceed in the following order : —

- 1st. Draw VH the vanishing trace for all horizontal planes.
- 2d. Find v^{ab} , the vanishing point for all horizontal lines in the house that vanish to the right.
- 3d. Find v^{ad} , the vanishing point for all horizontal lines vanishing to the left.
- 4th. Find v^{on} . The line on forms the intersection of the planes N_1 and U_1 (see oblique projection). To this same system belong the lines rq , ts , and zy .
- 5th. Find v^{um} . The line um forms the intersection of the planes M_1 and U_1 (see oblique projection). To this same system belong the lines qp , vu , and xw .
- 6th. Find v^f . The line fl forms the intersection of the planes S and V_1 . The line jk also belongs to this same system.
- 7th. Find v^g . The line lg forms the intersection of the planes R and V_1 . The line kh also belongs to this system.

8th. Find v^{dj} . The line dj forms the intersection of the planes P and M. To this same system belongs the line which forms the intersection of the planes P and M_1 .

9th. Find v^{eb} . The line gb forms the intersection of the planes N and O. To this same system belongs the line which forms the intersection between the planes N_1 and O.

10th. Draw the vanishing traces of the planes M, N, O, P, R, S, U, and V, checking the construction of the vanishing points already found.

11th. v^{af} will now be determined by the intersection of TP and TN (§ 74). The lines forming the intersection of the plane P with the planes N and N_1 will vanish at v^{af} .

In a similar manner v^{he} will be determined by the intersection of TM and TO. The lines forming the intersections of the plane O with the planes M and M_1 will vanish at v^{he} .

The complete vanishing point diagram has now been found; and it remains only to establish VH_1 in accordance with the given data, and construct the perspective projection of the house. A bird's-eye view has been chosen for the perspective projection in order to show as many of the roof lines as possible.

Each visible line in the perspective projection should be continued by a dotted construction line, to meet its particular vanishing point.

This problem will require more care in draughting than any of the previous ones, and the angles of the lines in revolved plan and elevation should be laid off with great precision. The student should not attempt to make the perspective projection until the vanishing point diagram is drawn with accuracy.

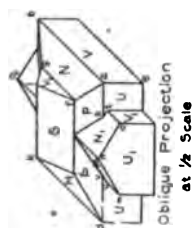
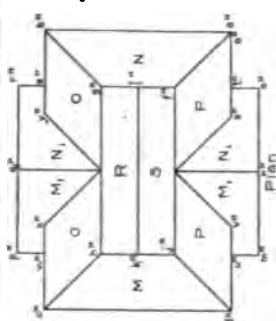
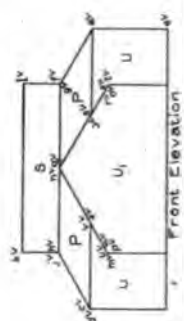
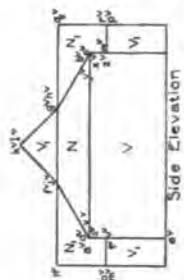
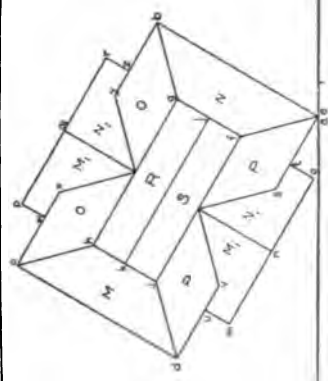
PLATE V.

PROBLEM XVII.

From the given data construct a perspective projection, using the plan of view for a diagram as indicated. HPP, VH_1 , SP^v , and SP^H are given.

This plate need not be lettered, except as the student may find it an aid in construction.

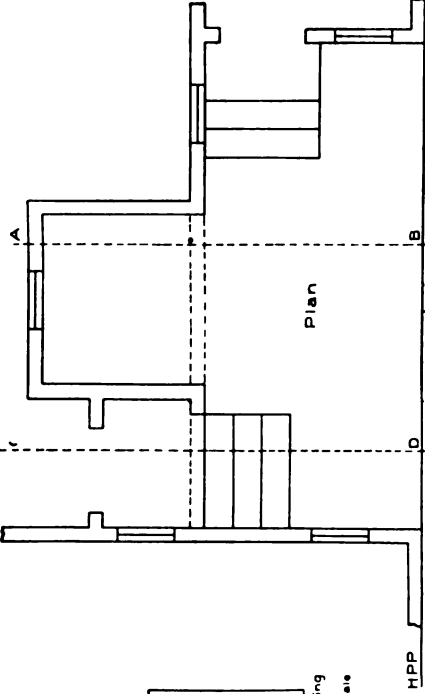
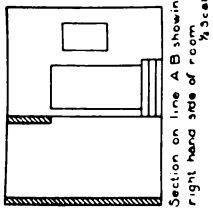
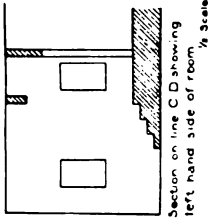
PLATE IV



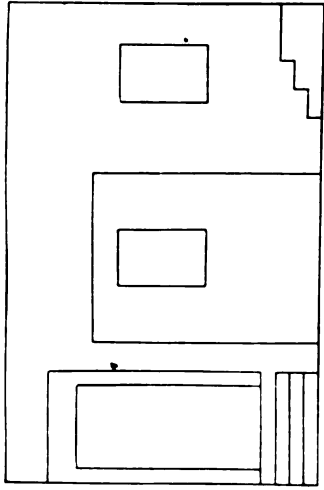
DATE _____

NAME

XVII



HPP



YH

DATE

NAME

PLATE VI.

PROBLEM XVIII.

Construct, by the method of perspective plan, a perspective projection of the object shown in the given plan and elevations.

HPP and VH are to be taken coincident (§ 107), as indicated on the plate.

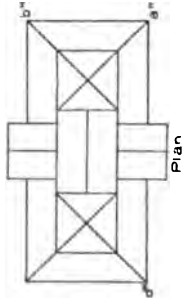
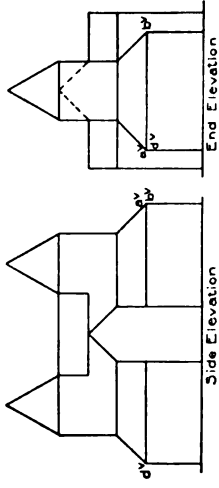
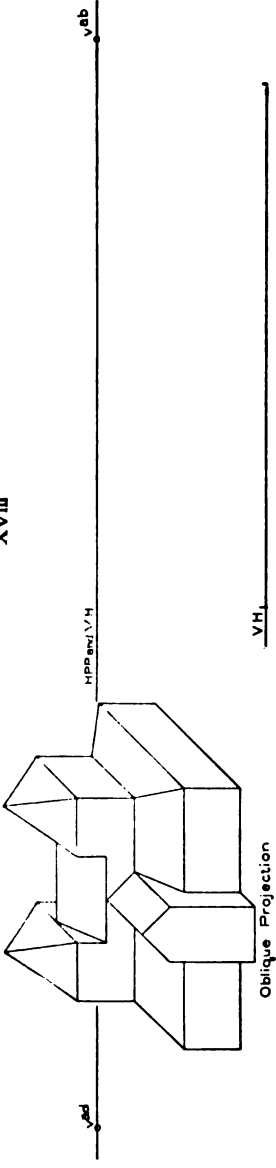
The vanishing points (v^{ab} and v^{ad}) for the two systems of horizontal lines in the object are given. The line ab is to make an angle of 60° with the picture plane.

VH_2 is the vertical trace of the horizontal plane on which the perspective plan is to be drawn. The corner (a'') of this plan is given. The perspective projection of the object is to rest on the horizontal plane determined by VH_1 .

An oblique projection of the object is given to assist in reading the plan and elevations.

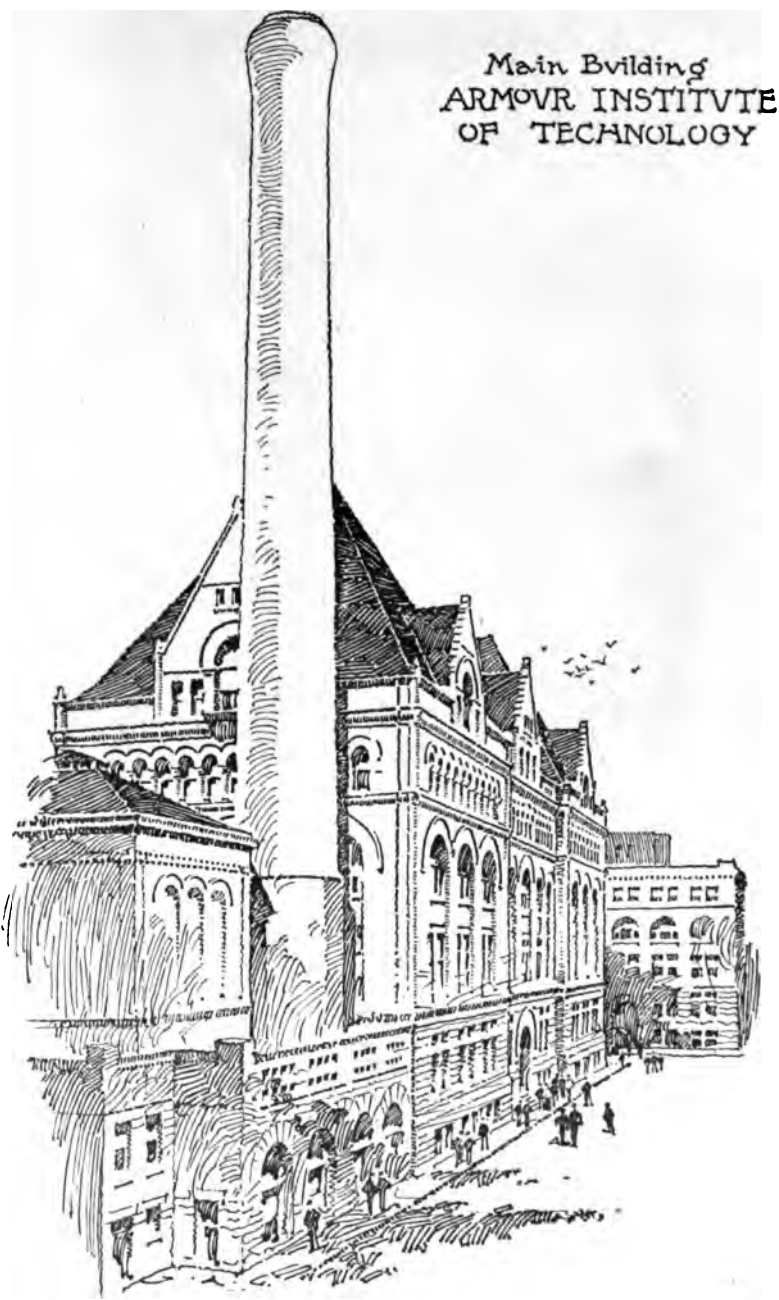
The student may use his discretion in lettering this plate. No letters are required except those indicating the positions of the station point and the measure points.

XV/III



DATE

NAME



A STUDY IN PEN AND INK RENDERING.

(For a different treatment of the same building, see page 362.)

RENDERING IN PEN AND INK.



To render in pen and ink a large and important drawing is no small accomplishment. Usually years of experience are necessary before one can successfully undertake such drawings. Now and then a student is to be found having talent to the extent that the attainment of this skill seems a very easy matter, but in general this talent is comparatively rare. Ninety-five out of every hundred have a long task ahead before success is possible. This difficulty of attainment, however, makes the accomplishment all the more valuable. No one would expect to

learn engraving on wood in a few brief lessons, and yet in pen and ink rendering difficulties are to be met not unlike those connected with engraving.

But there are many things concerning pen and ink work which can be readily learned; they are worth the trouble and the labor expended, and may prove useful. A consideration of these will, in any case, introduce the art and serve also as a good foundation for further pursuit of the subject if desired.

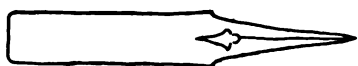
It is the purpose of this paper to seek the most modest of results, which may be set forth thus,—the rendering of a small building at a small scale in the very simplest manner, with few or no accessories.

Kind of Drawing. There are three ways in which a sketch may be rendered, viz: with pen, pencil, or brush. Pen rendering will be considered first, and later additional notes will be made as to pencil work. Rendering with the brush is another line of work,

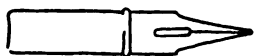
but much that may be advised in regard to pen rendering would also apply to brush work.

MATERIALS.

Pens. The tendency of beginners is to use too fine a pen. It must be remembered that many pen drawings are reproductions much smaller than the originals, and consequently the lines appear much finer than in the drawing itself. There are two pens that can be recommended, shown herewith. Years of experience prove them to be perfectly satisfactory. Occasionally a finer pen is needed, such as Gillott No. 303. The Esterbrook No. 14, a larger pen, is necessary in making the blacker portions of a drawing. The Gillott 404 is to be used for general work in the same drawing.



ESTERBROOK BANK
PEN, NO. 14.



GILLOTT NO. 404.

Ink is not of as much importance as pens. The various prepared India inks put up

in bottles are all that can be desired. They are more convenient than ink that must be rubbed up, and they have the advantage of always being properly black. Some ordinary writing inks serve the purpose very well if reproduction is not an object, but if reproduction is desired, India ink, being black, is preferred.

Paper. The very best surface is a hard Bristol board. The softer kinds of Bristol boards should be avoided, as they will not stand erasure. Most of the drawing papers do very well. Whatman's hot pressed paper is very satisfactory. An excellent drawing surface is obtained by mounting a smooth paper on cardboard, thus obtaining a level surface that will not spring up with each pressure of the pen. This is equivalent to a Bristol board. However, the size of Bristol board is limited and frequently drawings must be much larger, in which case the mounted paper is a necessity.

LINE WORK.

Quality of Line. Too much stress cannot be laid on the importance of a good line, however insignificant it may seem. Care in each individual line is absolutely necessary for good work. A line



GOOD QUALITY OF LINE.

that is stiff and hard, feeble, scratchy or broken, will not do. Such work will ruin a drawing that in other respects may be excellent. The accompanying illustration by one of the students of the Massachusetts Institute of Technology is an example of excellent quality of line. Each line, even to the very smallest, has grace and beauty. By a very few, the ability to make such lines is speedily acquired—but by a few only—others may attain it by careful practice.

Every line of a drawing—the outline of the building and each line of the rendering, even to the very shortest must be done feelingly, gracefully, positively. Usually a slight curve is advisable and if long lines are used, a quaver or tremble adds much to the result. Each line of a shadow should have a slight pressure of the pen at the lower end. This produces a dark edge in the group of lines that



make the shadows, giving definiteness to the shadow and contrast to the white light below it.

Method. The combination of individual lines produces what we may term a method. The individual line may be good but the combining may be unfortunate. In making a wash drawing no thought is necessary concerning the direction of the wash, but in using lines at once the query arises as to what direction they



A DORMER, GERMANY.

EXCELLENT METHOD

shall take. A method is something one must grow into from a small, simple beginning. The accompanying illustration, the work of another Massachusetts Institute of Technology student, is an example of rare skill in method quickly acquired. There is an utter absence of anything rigid or mechanical in the whole. Observe how softly the edges of the drawing merge into the white of the paper. The vigor of the drawing is gathered in the dormer itself.

Vertical Lines. The simplest method is obtained by the use of the vertical line. Some drawings can be made entirely by this means. See Fig. 3, every line of which is vertical. This illustrates the value of a good individual line. It will be observed that although vertical, these lines are not severely straight and stiff, they tremble a little, or have a slight suggestion of a curve. In the shad-



Fig. 3.

VERTICAL LINE METHOD.

ow at the bottom of the drawing each line is emphasized at the top by a slight pressure, and made thin at the lower end in order to soften off the edges of the drawing as a whole.



Fig. 4.

FREE LINE METHOD.

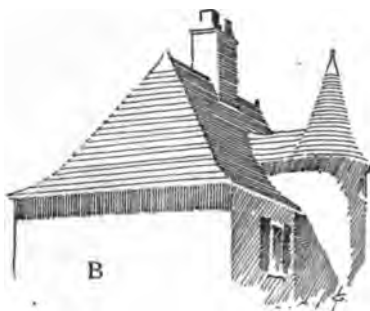
Free Lines. Fig. 4 shows another method. The vertical line is discarded and the freest possible line is used. No one direction is followed, but the lines go in any or all directions. Which

is the better method? The answer doubtless must be that the free method is the least conspicuous. It is better adapted for general use, in the showing of various surfaces and textures.

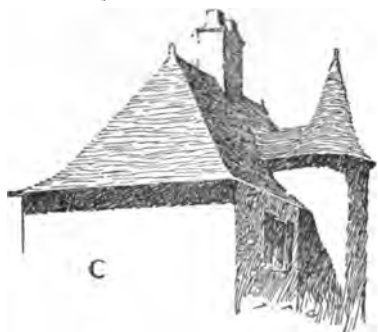
VARIOUS EXAMPLES OF METHODS.



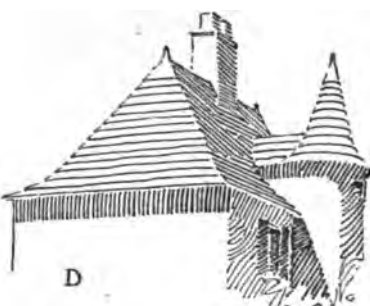
Short, broken line, resulting in a spotty effect; a fault common with beginners. The white spaces between the ends of the lines are very conspicuous.



The opposite in character to A. Long, unbroken lines, but so severely straight as to be hard and dry in general appearance.



Short lines, individually they may be very good, as they curve freely, but the combination is fussy and finicky.



Direction of line not bad, but is rather too coarse to be agreeable. Wide spacing of lines on light portions add to the coarse result.

These illustrate four bad methods. A has the least merit, the others approach to a fair quality. In E an effort is made to avoid all the faults shown in the others—the short or severely straight line, the over labor combination of C, and the coarse line of D.

LIGHT AND SHADE.

Values. If several lines are drawn parallel and quite close together, but not touching, a gray, or half-tone value is the result.

Lines drawn so close together that the ink of one runs into that of the other, with little or no white space between, give a black



value. The white of the paper untouched by the pen gives a white value. Fig. 5 shows only two values—black and white; Fig. 6 also has two.—gray and white; Fig. 7 has the three,—black, gray and white. The first is harsh, the second is pale, and the third seems most satisfactory.

This is a safe rule to follow—get into every pen drawing, black, gray and white. Usually, in early attempts, there is a tendency to omit the black. Look for the place in the

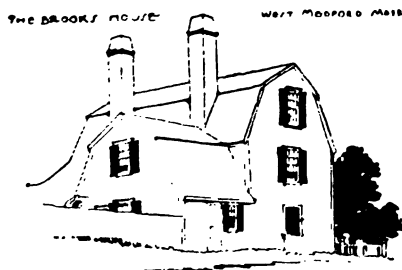


Fig. 5.
BLACK AND WHITE.



Fig. 6.
GRAY AND WHITE.



Fig. 7.
BLACK, GRAY AND WHITE.

drawing where you can locate this black; you are not likely to get too much of it. Let the half tone or gray be rather light, mid-way in strength between white and black. A heavy half tone is



Fig. 8.
ONE SIDE IN SHADE.

a dangerous value. The black may often grade off into the gray, or there may be distinct fields or areas of each value.

Lighting. The first thing to consider in the rendering of an architectural subject is the choosing of the direction of light. Sometimes when the building is turned well to the front, showing



Fig. 9.
ALL IN LIGHT.

a sharp return of the end, it may be best to put that side in shade, Fig. 8, but it is not necessary. Values may be obtained by other means such as by shadows, or color of material. It is not wise to attempt a heavy rendering in pen work. Usually it is safer

to keep both sides of the building in light as shown in two of these sketches, Figs. 9 and 10.



Fig. 10.

ALL IN LIGHT WITH HALF-TONE VALUE TO ROOF.

Color of Material. One of the means by which values may be introduced into a rendering, is by considering the color of the material of which the building is constructed.



Fig. 11.

HALF-TONE WALLS.

In this example, Fig. 11, we may first use the brick walls as a place to locate a gray value. In the second example, Fig. 12, the roof is used for the same value. For the very dark or black value we must depend on the shadows. Neither one of these draw-

ings is wholly satisfactory. In the first, the roof, and in the other, the walls, seem too glaringly white. For that reason it is not always best to use the material color so broadly. To give color to

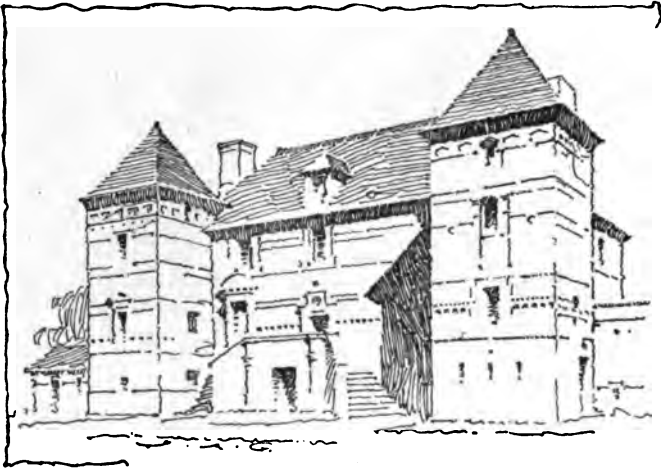


Fig. 12.
HALF-TONE ROOF.

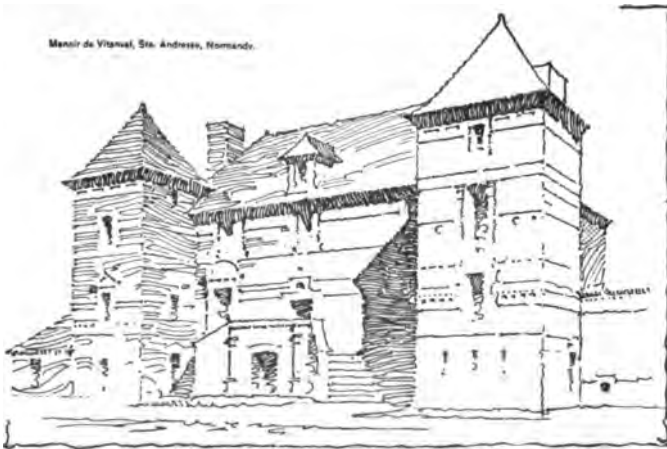


Fig. 13.
A COMPROMISE.

both walls and roof would destroy the white value, and the white value must not be lost. Fig. 13 shows an attempt at a compromise.

Shadows Only. The simplest means for obtaining values is

by the use of shadows. Sometimes the shadows alone will complete a drawing in a very satisfactory manner, as in Fig. 14. Some of the shadows may be made gray, and others black or nearly so, in order to get the needed variety in values.

A building like that shown in Fig. 15, The Alden House, is not favorable to shadows only. It has no porch or other projection sufficiently large to cast a strong shadow. In such a case a little accessory helps one out of the difficulty, and a little rendering of the material gives needed half tone. Otherwise the drawing would be too white.

Principality or Accent. We now enter into a matter of composition. One simple rule will be given and there is none more useful. Let there be one place in the drawing where a strong accent of black shall exist. It may be one black, or it may be a group of them. This accent will be found in nearly every illustration in this paper. It is usually best to



Fig. 14.
SHADOWS ONLY.

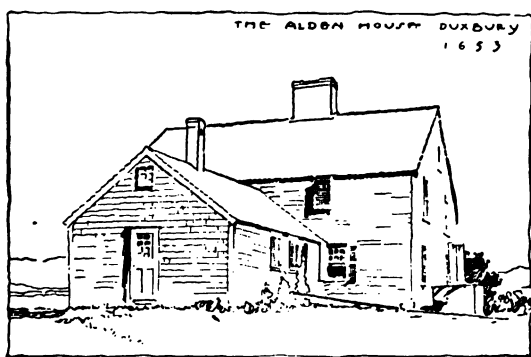
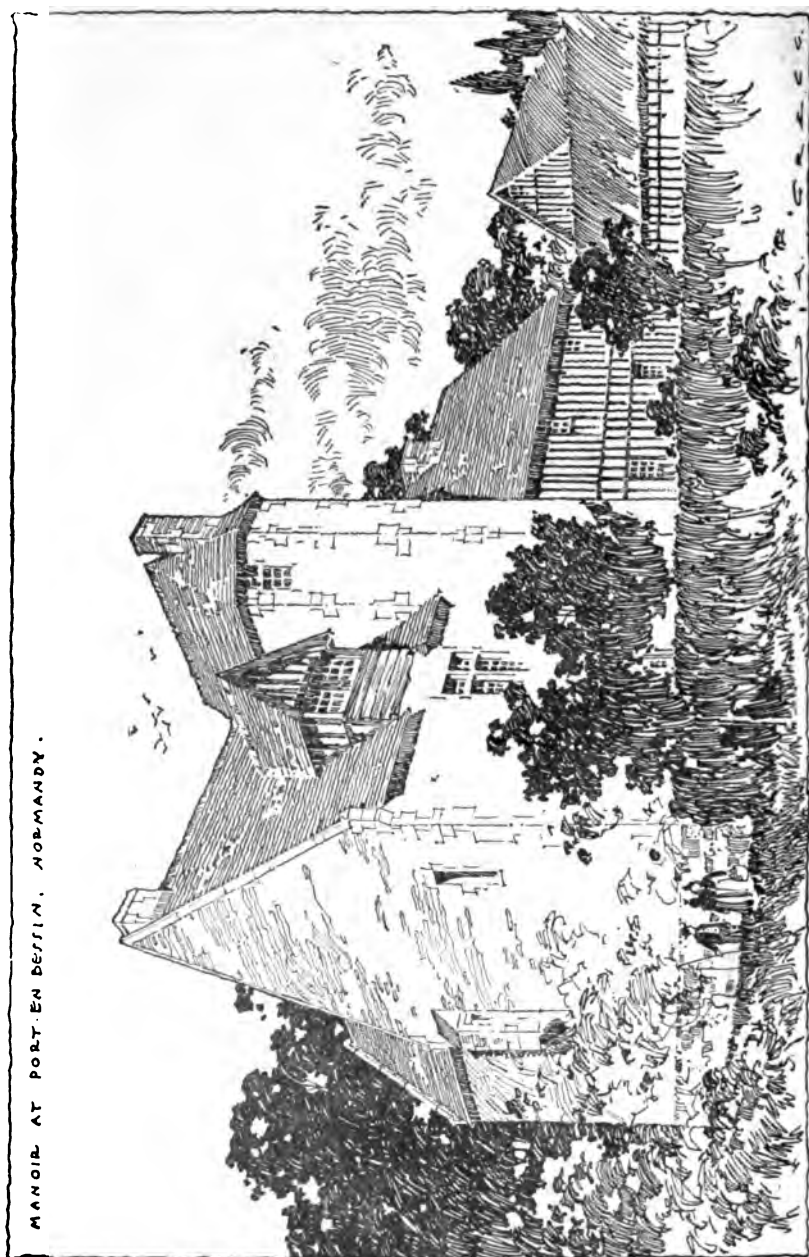


Fig. 15.

get the accent in the building itself, by the aid of some large shadow perhaps, but when there is no chance for this it may be necessary to get it in an accessory such as foliage. This is shown in Fig. 16, a drawing of a barn. In connection with this black accent let there be a large white area if possible. A princi-



MANOIR AT PORT-EN-BESSIN, NORMANDY.

FIG. 17.

pal white, as well as a principal black is thus obtained. Most drawings permit the dark accent and the light area also.

Fig. 17 is rendered to a greater extent than should be attempted by the student in this course, but it may be helpful to call attention to some things in its composition.

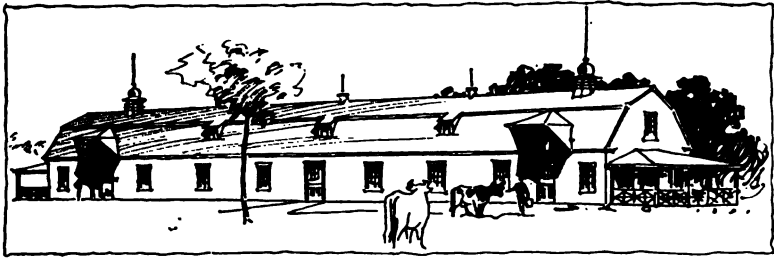


Fig. 16.

The location of the dark accent is apparent in the trees at the left. The other blacks, the trees in front of the building and those down at the extreme right, simply repeat in diminishing force and size, this first dark accent. The light area of the drawing is as distinctly shown as the dark accent; in fact this large light is the feature of this rendering. The light brick rendering of the gable is necessary to confine the light a little more surely to the important portion of the wall. Also, if this light rendering were omitted the building would appear unpleasantly white.

The half tone of the roof is necessary to give a soft contrast to the light wall surface. The sky has its use. Cover it up, and see how the whole subject slumps downward.

Last, but not least, observe that the corners of the drawing are kept free from rendering. This is usually safe. Let the rendering of every sort gather about the central object. The corners of a drawing may then be left to take care of themselves.

PENCIL WORK.

A pencil is a quicker medium for the rendering of a sketch than a pen. A pencil sketch may be made directly on a sheet of drawing paper, and completed on that same sheet. But it is neater to first draw the perspective on smooth white paper, then place Alba tracing paper over this outline, and trace and render. By this means all construction lines in the layout can be omitted,

and the sunny edge of projections can be left out, thus adding greatly to the brightness of the drawing.

Use a soft pencil for rendering, a BB or softer. If the drawing is to be much handled, spray it with fixatif. Trim the sketch, lightly gum the corners, and lay on white card with good margins.

SUMMARY.

The following summary of advice for the rendering of work generally, with pen or pencil may be found helpful.

1. Consider the direction of the light.
2. Discover in the outline before you, the opportunity for a leading dark accent.
3. Look out also for the location of a large light area.
4. Put in shadows.
5. Get at least three distinct values; black, gray and white.
6. Consider the color of roof or the wall, and if necessary use one of them or portions of each for a gray value.
7. Use a very free method.
8. Keep rendering out of the corners of the drawing.



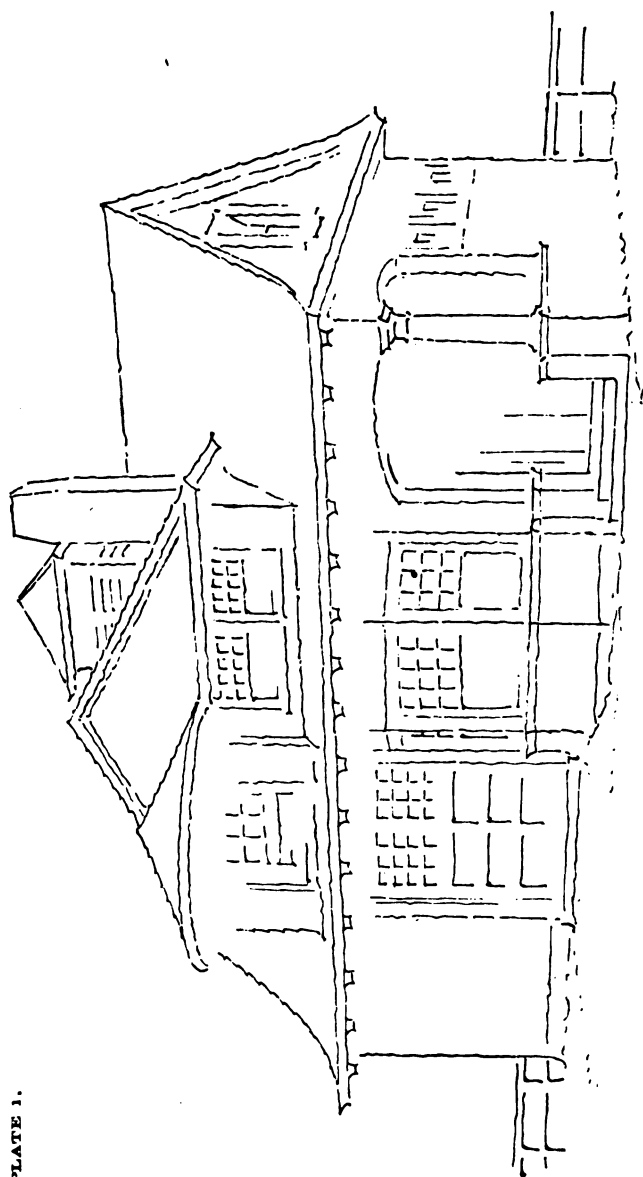


PLATE 1.

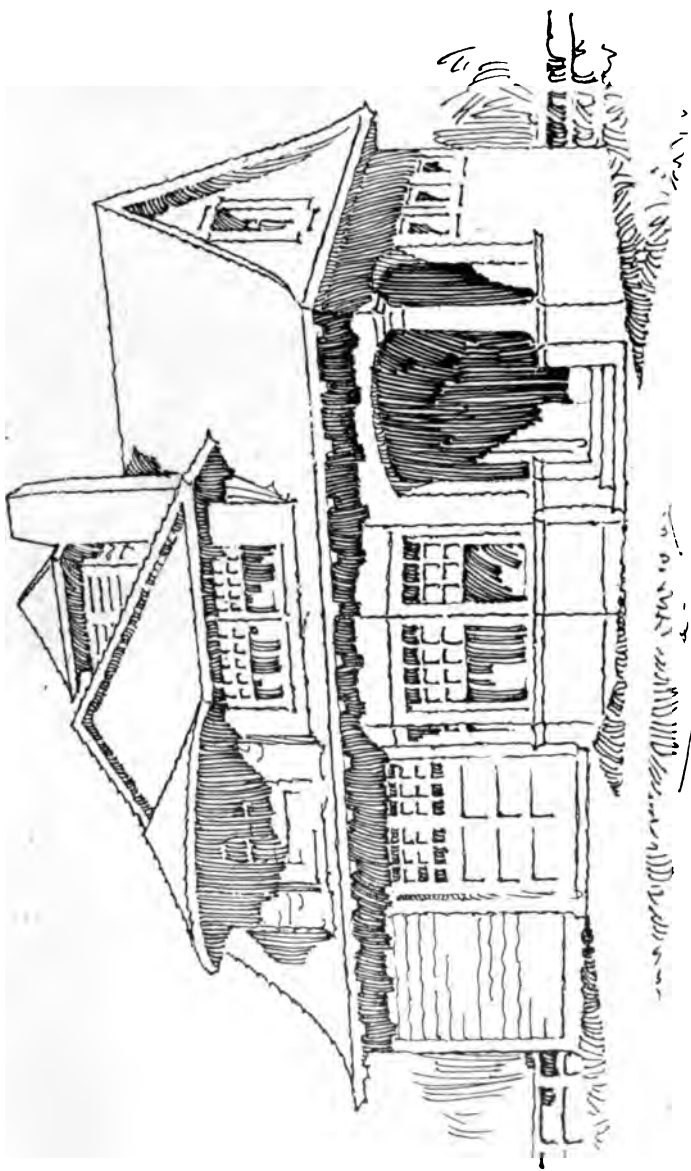


Fig A. (For Plate I.)

FINISHED DRAWING.

EXAMINATION PLATES.

Before attempting to render the drawings in ink, the student is advised to practice both with pencil and ink, using the practice plates provided for the purpose.

PLATE I.

In order to get quickly into the practice, the student will be asked to make a copy of this rendering, Fig. A. Do not try to copy too exactly, but use the same freedom.

Observe that the dark accent is obtained by the large shadow and the end of the long shadow just over it. The dark rendering in the window is brought into the group also.

Having thus formed the accent, it is best that the shadow under the hood in the roof should be made rather light, lest it come into competition with the porch shadow. If the student prefers he may make it a trifle darker than here shown.

A little clapboard rendering is put in on the left, to make still more evident the large light, which occurs mainly on the roof but at the same time takes in other white spaces at that end of the drawing.

PLATE II.

This subject introduces a roof rendering, also a simple treatment of windows and blinds. Here the roof serves as a half-tone value. The shadow of the eaves and some of the blinds are the black values. To get the dark accent, the nearest blinds and the near portion of the shadow on the eaves are made very dark.

The shadow under the porch shows how safely much of the detail of the door itself may be omitted and not be missed. A broad treatment is better than a fussy one. Observe that the roof lines are made as free as possible, avoiding a straight, wiry line.

After copying this plate original work may be attempted.

PLATES III AND IV.

Make the shadows only for the first rendering, Plate III, just as shown in this value scheme, Fig. C. Then make a second drawing of the same, Plate IV, and give a half tone to the front area of the roof, and to the end of the roof a darker value, as shown in suggestion in upper corner. Finally on this second

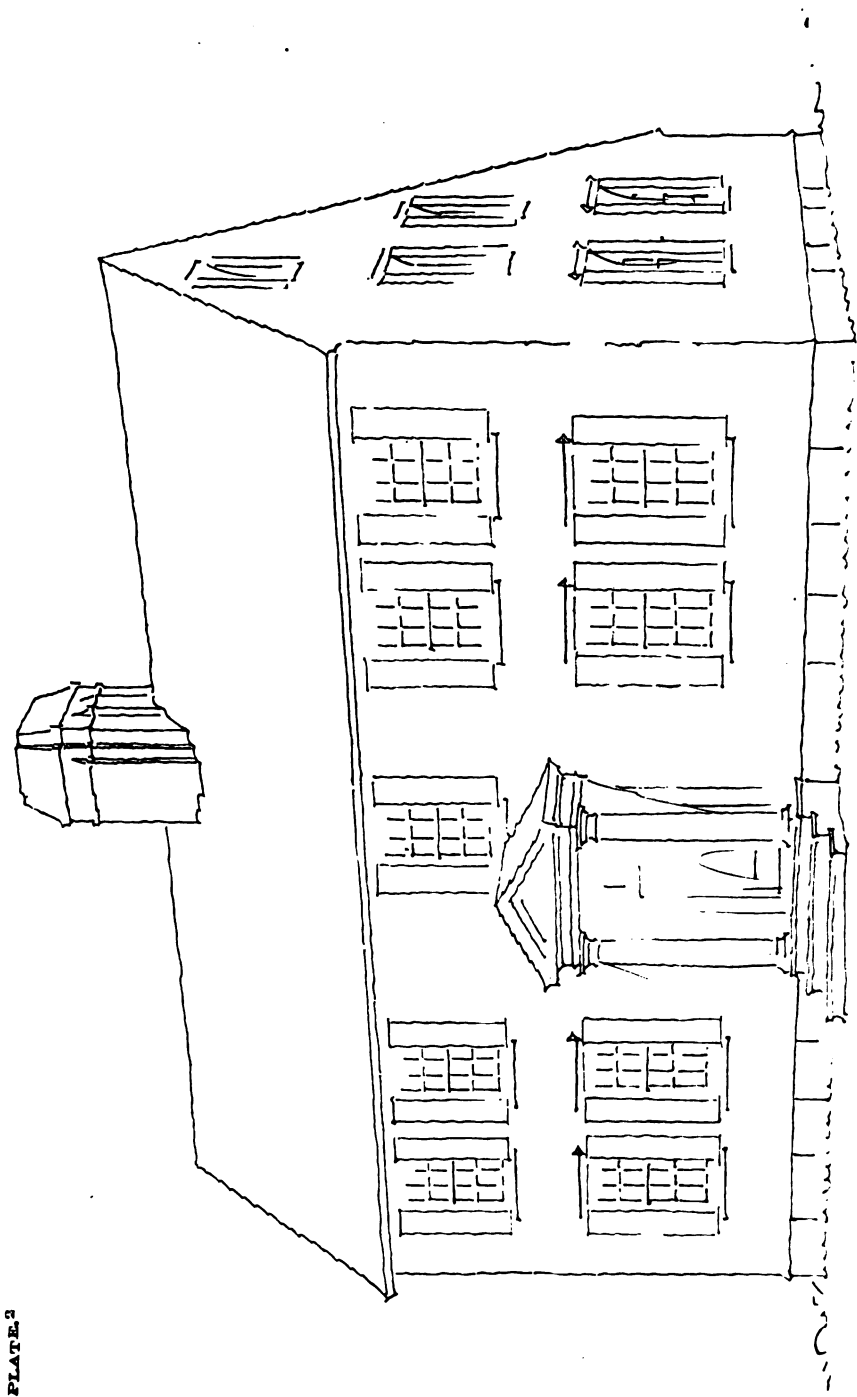


PLATE 2

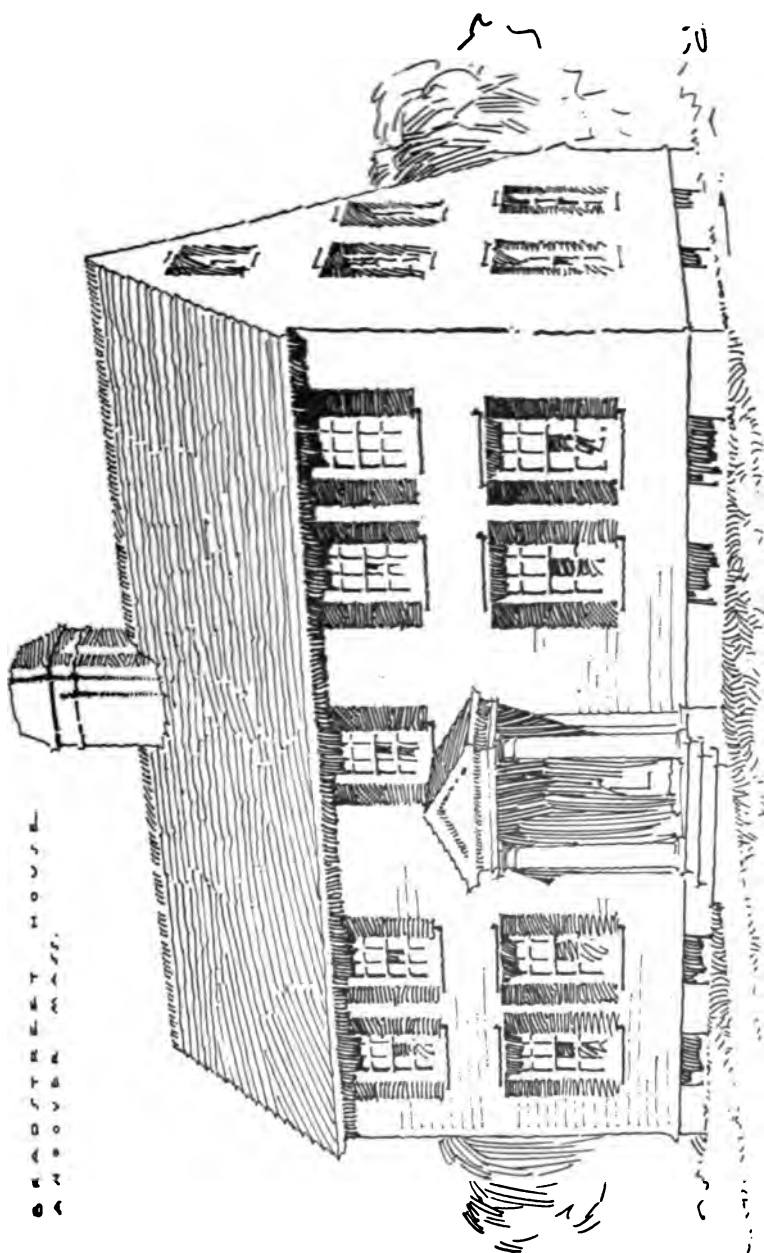
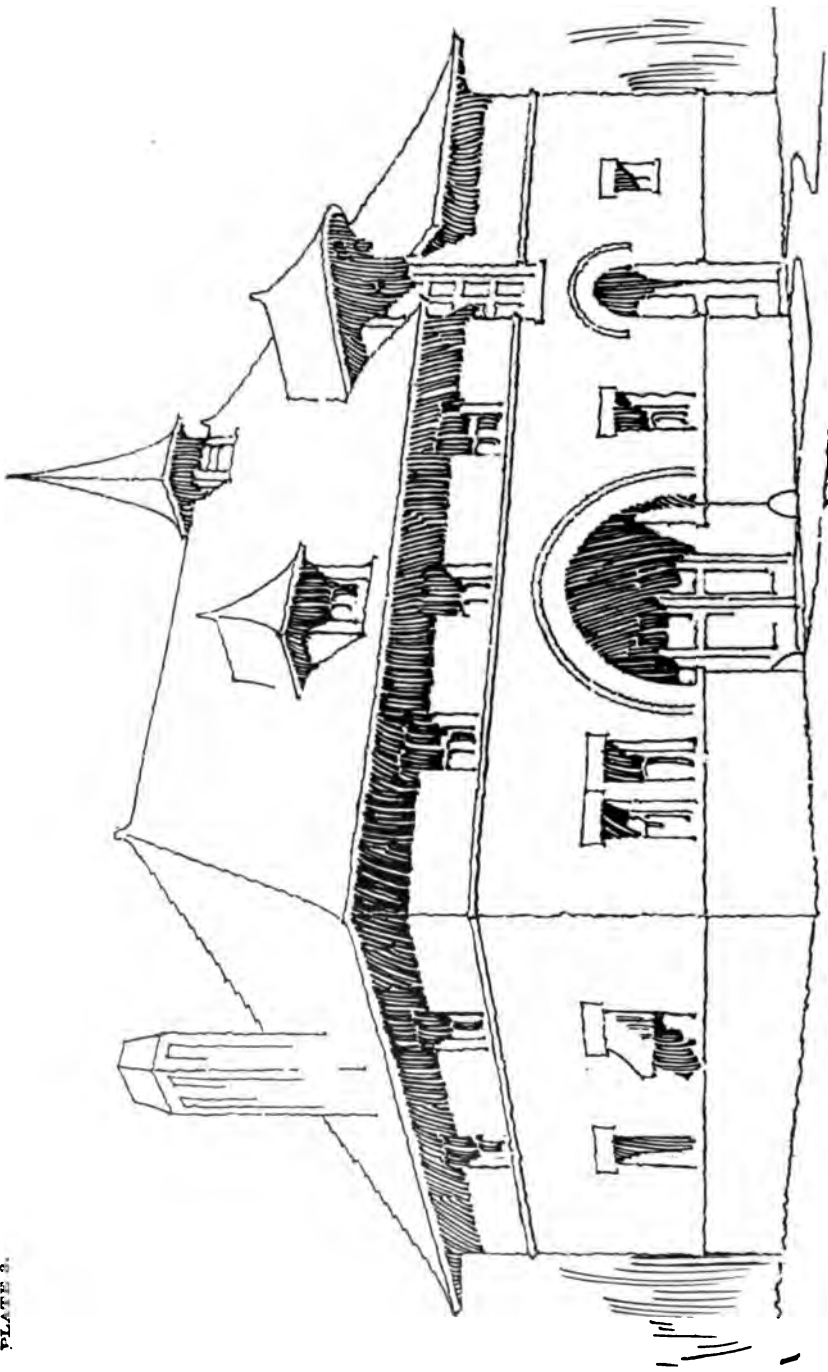
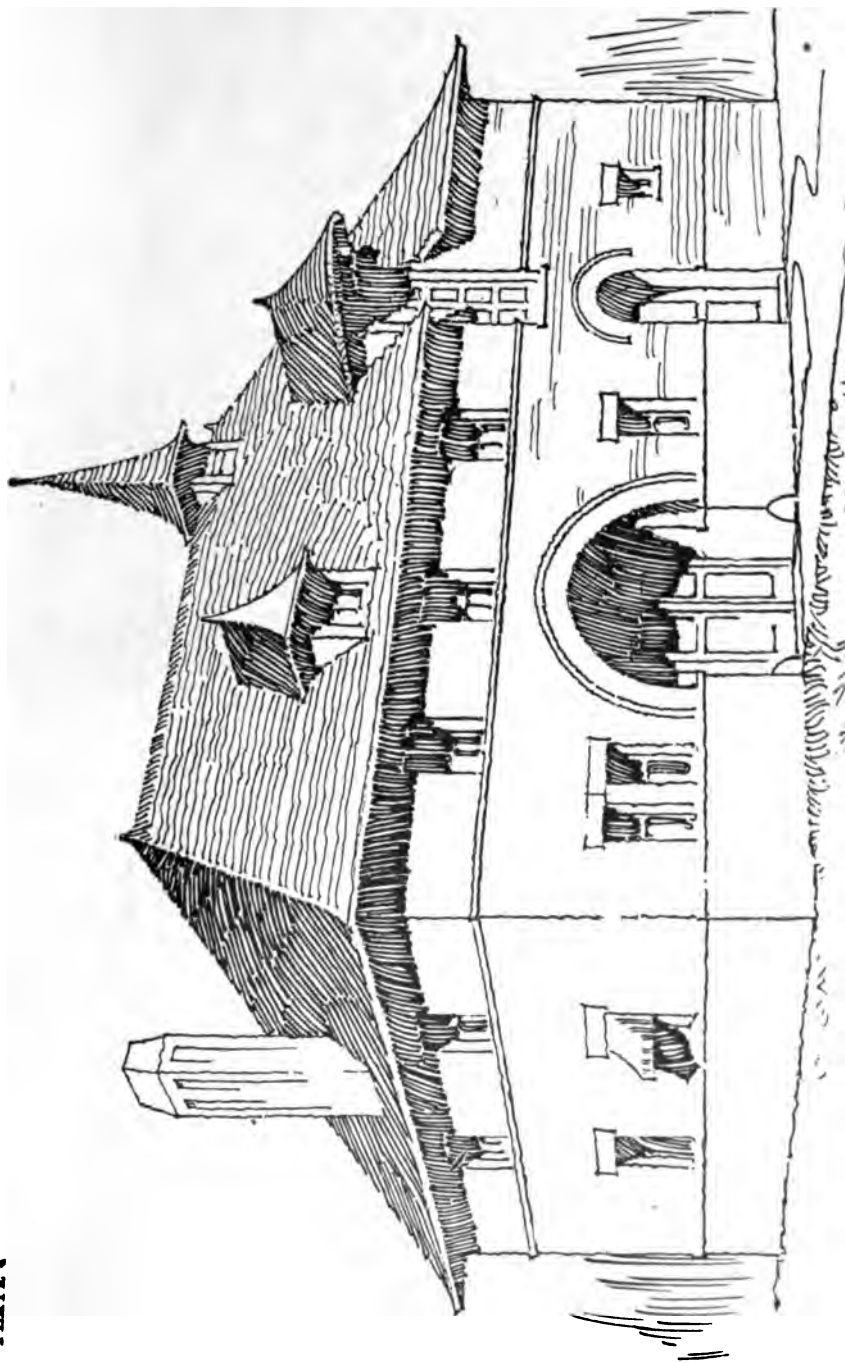


Fig. B. (For Plate II.)

PLATE 3.



D. A. C. R. E. C. C.



TWO DIFFERENT TREATMENTS OF SAME SUBJECT.

(See opposite page.)

W. D. A. C. 1866

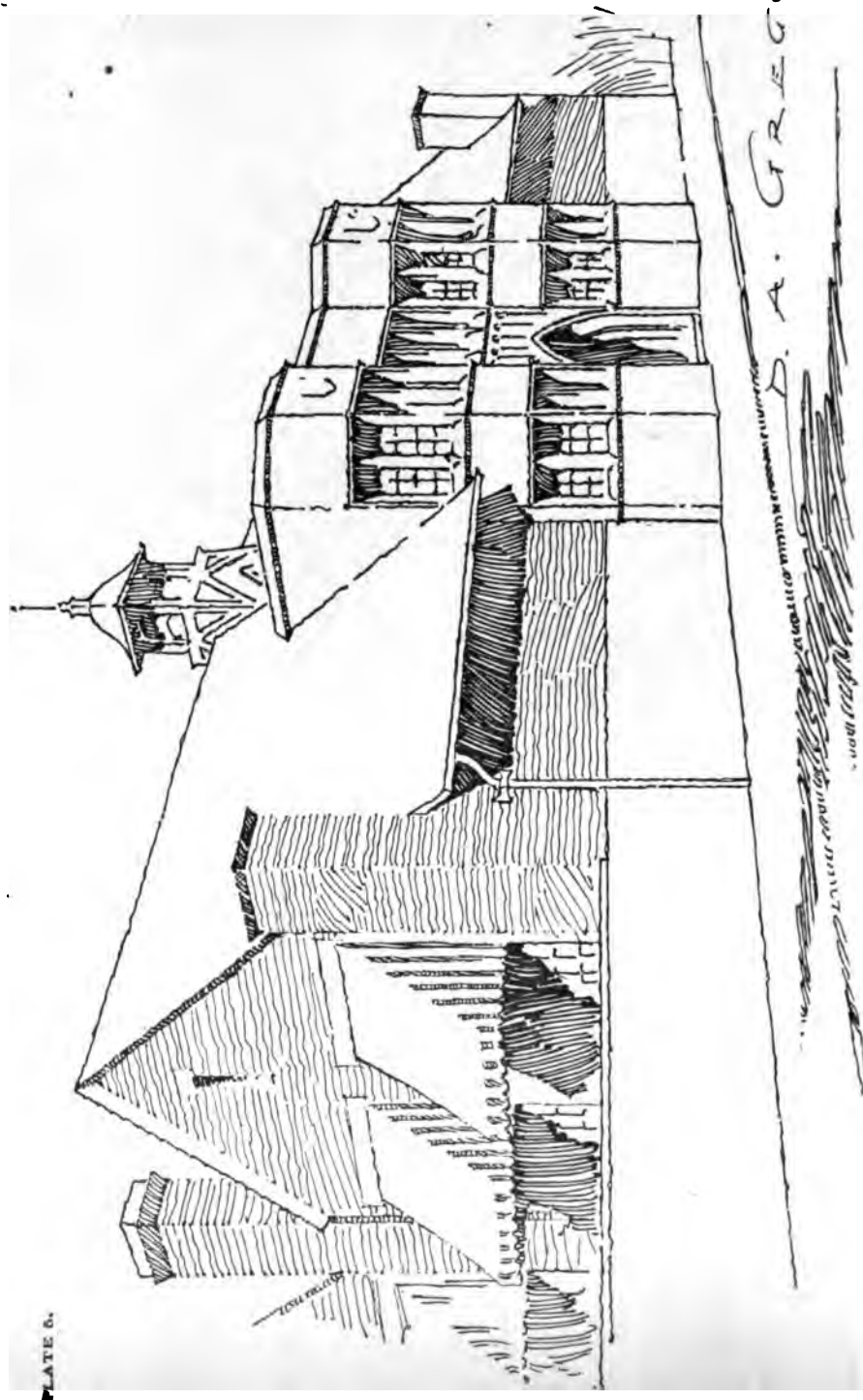


PLATE 6.

drawing, put a small amount of rendering on the wall at the distant right, in the same manner as on Plate II. This will give a large white light on the walls nearest the observer. The long shadows under the eaves should be darkest at the corner nearest the observer and gradually lighten up as it approaches either end.

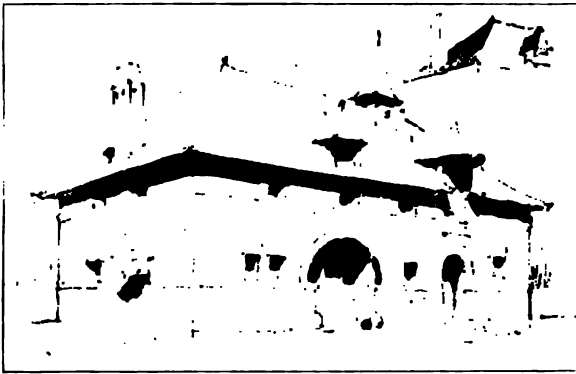


Fig. C. (FOR PLATES III AND IV.)

PLATE V.

Put in the shadows first. Get the nearest shadows very dark; then give a half-tone rendering to the whole of the brick-wall surface. Do not ink in the lines at the edges of the brick walls. Let



Fig. D. (FOR PLATE V.)

your rendering make the edge as shown in Fig. 18. An outline in such a place produces a mechanical looking rendering, as is seen in the illustration. Outlining is absolutely necessary where there

is no rendering, but in connection with it, omit the outline, if possible.

PLATE VI.

The doorway shadow selects for itself the honor of being the leading accent; the shadows at left and right simply repeat it in a small way. The roof affords an opportunity for half-tone. The

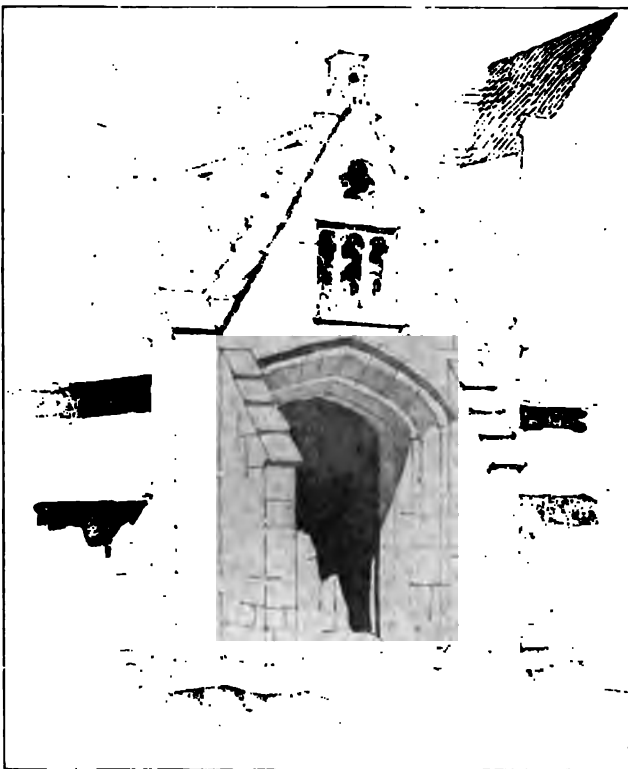


Fig. E. (FOR PLATE VI.)

grass, which may be rendered as illustrated in the two preceding examples, gives also an additional half-tone value. To retain or produce a large light area, the stone jointing should be omitted on the upper portion of the wall, as indicated in the scheme. The roof may be rendered in a free-line method, as shown in the sketch. With a good quality of line, and a free, vigorous method, this drawing will be a brilliant one, as its composition of values is favorable.



This ends the practice. Only a beginning has been made in the work—a foundation laid, but it is a safe one. What has been

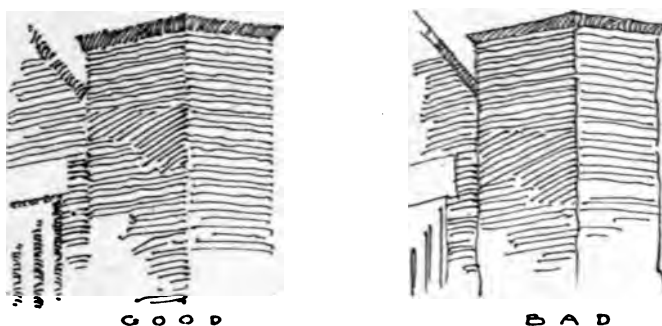


Fig. 18.

taught will be a help to a further pursuit of the subject should the student feel that he has developed sufficient talent to encourage further study.



Suggestion for treatment of house showing roof in light with half-tone value to walls.

FORMA
D'AVGVSTE

· ROME ·

ECHELLE
DE 0.002 M

AVGVSTVS PONTIFEX MAX TRIB POTEST X



DETAIL FROM TEMPLE OF MARS VENGEUR.

An example of classic lettering, conventional shadows and rendering.

Reproduced by permission of Massachusetts Institute of Technology.

ARCHITECTURAL LETTERING.

Architectural lettering may be divided into two general classes. The first is for titling and naming drawings, as well as for such notes and explanations as it is usual or necessary to put upon them; this may well be called "Office Lettering." The second includes the use of letters for architectural inscriptions to be carved in wood or stone, or cast in metal: for this quite a different character of letter is required, and one that is always to be considered in its relation to the material in which it is to be executed, and designed in regard to its adaptability to its method of execution. This may be arbitrarily termed "Inscription Lettering," and as a more subtle and less exact subject than office lettering it may better be taken up last.

OFFICE LETTERING.

Architectural office lettering has nothing in common with the usual Engineering letter, or rather, to be more exact, the reverse is true: Engineering lettering has nothing in common with anything else. Its terminology is wrong and needlessly confusing inasmuch as it clashes with well and widely accepted definitions. Therefore it will be necessary to start entirely anew, and if the student has already studied any engineering book on the subject, to warn him that in this instruction paper such terms as Gothic, etc., will be used in their well-understood Architectural meaning and must not be misinterpreted to include the style of letter arbitrarily so called by Engineers.

The first purpose of the lettering on an architectural plan or elevation is to identify the sheet with its name and general descriptive title, and further, to give the names of the owner and architect. The lettering for this purpose should always be rather important and large in size, and its location, weight and

height must be exactly determined by the size, shape and weight of the plan or elevation itself, as well as its location upon and relation to the paper on which it is drawn, in order to give a pleasing effect and to best finish or set off the drawing itself. The style of letter used may be suggested, or even demanded, by the design of the building represented. Thus Gothic lettering might be appropriate on a drawing of a Gothic church, just as Italian Renaissance lettering would be for a building of that style, or as Classic lettering would seem most suitable on the drawings for a purely Classic design; while each letter or legend would look equally out of place on any one of the other drawings.

LETTER FORMS.

It may be said that practically all the lettering now used in architectural offices in this country is derived, however remotely it may seem in some cases, from the old Roman capitals as developed and defined during the period of the Italian Renaissance. These Renaissance forms may be best studied first at a large size in order to appreciate properly the beauty and the subtlety of their individual proportions. For this purpose it is well to draw out at rather a large scale, about four or four and one-half inches in height, a set of these letters of some recognized standard form, and in order to insure an approximately correct result some such method of construction as that shown in Figs. 1 and 2 should be followed. This alphabet, a product of the Renaissance, though of German origin, is one adapted from the well-known letters devised by Albrecht Dürer about 1525, and is here merely redrawn to a simpler constructive method and arranged in a more condensed fashion. This may be accepted as a good general form of Roman capital letter in outline, although it lacks a little of the Italian delicacy of feeling and thus betrays its German origin.

The letter is here shown in a complete alphabet, including those letters usually omitted from the Classic or Italian inscriptions: the J, U (the V in its modern form) and two alternative W's, which are separately drawn out in Fig. 1.

These three do not properly form part of the Classic alphabet and have come into use only within comparatively modern

times. For this reason in any strictly Classic inscription the letter I should be used in place of the J, and the V in place of the U. It is sometimes necessary to use the W in our modern spelling, when the one composed of the double V should always be employed.

The system of construction shown in this alphabet is not exactly the one that Dürer himself devised. The main forms of the letters as well as their proportions are very closely copied from the original alphabet, but the construction has been somewhat simplified and some few minor changes made in the letters themselves, tending more towards a modern and more uniform character. The two W's, one showing the construction with the use of the two overlapping letter V's, and one showing the W incorporated upon the same square unit which carries the other

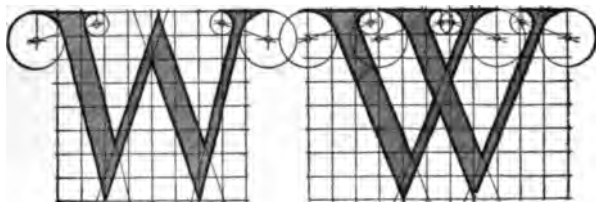


Fig. 1. Two Alternative Forms of the Letter W, to accompany the Alphabet shown in Fig. 2.

letters (the latter form being the one used by Dürer himself), are shown separately in Fig. 1. It should be noticed that every letter in the alphabet, except one or two that of necessity lack the requisite width—such as the I and J—is based upon and fills up the outline of a square, or in the case of the round letters, a circle which is itself contained within the square. This alphabet should be compared with the alphabet in Fig. 4, attributed to Sebastian Serlio, an Italian architect of the sixteenth century. By means of this comparison a very good idea may be obtained of the differences and characteristics which distinguish the Italian and German traits in practically contemporaneous lettering.

After once drawing out these letters at a large size, the beginner may find that he has unconsciously acquired a better constructive feeling for the general proportions of the *individual* let-

ters and should thereafter form the letters free-hand without the aid of any such scheme of construction, merely referring occasionally to the large chart as a sort of guide or check upon the

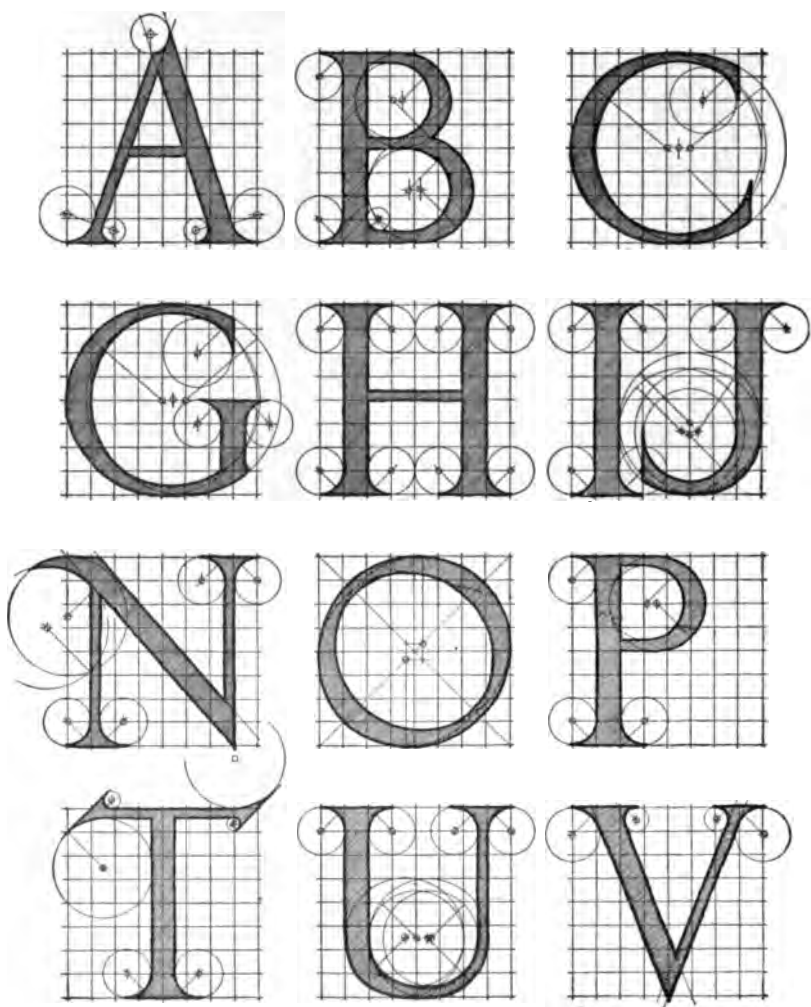


Fig. 2. Alphabet of Classic Renaissance Letters according to Albrecht Dürer, adapted and reconstructed by F. C. Brown. (See Fig. 1.)

eye. For this purpose it should be placed conveniently, so that it may be referred to when in doubt as to the outline of any individual letter. By following this course and practicing thor-

oughly the use of the letters in word combinations, a ready command over this important style of letter will eventually be acquired.

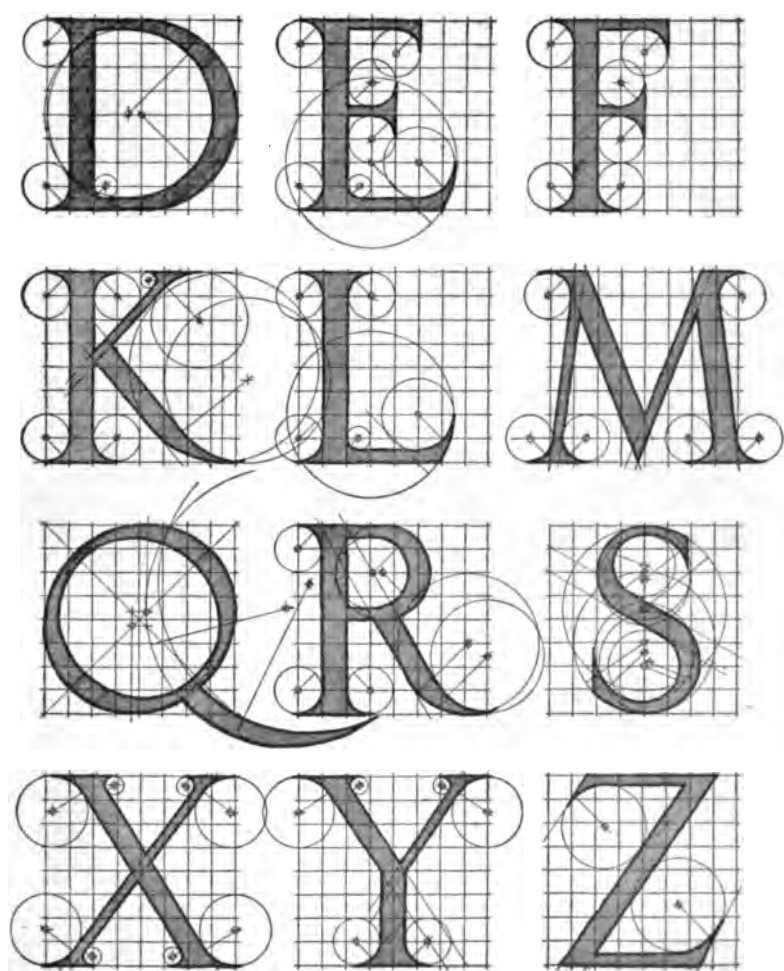


Fig. 2. (Continued)

In practice it will soon be discovered that a letter in outline and of a small size is more difficult to draw than one solidly blacked-in, because the defining outline must be even upon both

its edges; and that as the eye follows more the inner side of this line than it does the outer, both in drawing and afterwards in recognizing the letter form, the inaccuracies of the outer side of the line are likely to show up against the neighboring letters, and produce an irregularity of effect that it is difficult to overcome, especially for the beginner; while in a solidly blacked-in letter, it is the outline and proportions alone with which the draftsman must concern himself. Therefore, a letter in the same style is more easily and rapidly drawn when solidly blacked-in than as an "open" or outline letter. In many cases where it is desired to give a more or less formal and still sketchy effect, a letter of the same construction but with certain differences in its characteristics may be used. It should not be so difficult to draw, and much of the same character may still be retained in a form that



Fig. 3. Title from Competitive Drawings for the Taunton Public Library, Albert Randolph Ross, Architect.

is much easier to execute. Some such letter as is shown at the top of Fig. 10, or any other personal variation of a similar form such as may be better adapted to the pen of the individual draftsman would answer this purpose. The titles shown in Figs. 3 and 5 include letters of this same general type, but of essentially different character.

In drawing a letter that is to be incised in stone it is customary to show in addition to the outline, a third line about in the center of the space between the outside lines. This additional line represents the internal angle that occurs at the meeting of the two sloping faces used to define the letter. An example is shown in Figs. 24 and 25, while in Fig. 7, taken from drawings for a building by McKim, Mead & White, the same convention is frankly employed to emphasize the principal lettering of a pen-drawn title.



Fig. 4. Italian Renaissance Alphabet, according to Sebastian Serlio.

For the purpose of devising a letter that may be drawn with one stroke of the pen and at the same time retain the general character of the larger, more Classic alphabet, in order that it may be consistently used for less important lettering on the same drawing, it is interesting to try the experiment of making a skeleton of the letters in Figs. 1 and 2. This consists in running a single heavy line around in the middle of the strokes that form

JERSEY · CITY · FREE · PUBLIC · LIBRARY
· SCALE · ONE · INCH · EQUALS · FOUR · FEET ·
 BRITE · AND · BACON · ARCHITECTS · III · FIFTH · AVENUE · NEW · YORK · CITY ·

Fig. 5. Title from Drawings for the Jersey City Public Library,
 Brite & Bacon, Architects.

the outline of these letters. This "skeleton" letter, with a few modifications, will be found to make the best possible capital letter for rapid use on working drawings, etc., and in a larger size it may be used to advantage for titling details (Fig. 9). It will also prove to be singularly effective for principal lettering

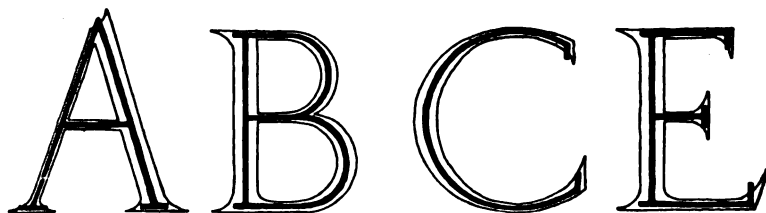


Fig. 6. "Skeleton" Construction of Letters shown in Fig. 2.

on plans, to give names of rooms, etc. (Fig. 13), while in a still smaller size it may sometimes be used for notes, although a minuscule or lower case letter will be found more generally useful for this purpose.

In Fig. 6 are shown four letters where the skeleton has been drawn within the outline of the more Classic form. It is un-

• THREE QUARTER INCH SCALE DETAIL, FRONT ELEVATION •
 • THE KNICKERBOCKER TRUST COMPANY •
 • COR 34TH ST & 5TH AVE •
 • MCKIM MEAD & WHITE ARCHITECTS • NO 160 FIFTH AVE NEW YORK CITY •



• NOTE • STONES IN FRIEZE SHOWN WITH TO BE REMOVABLE FOR FUTURE WINDOWS •

Fig. 7. Title from Drawing of Building for the Knickerbocker Trust Co., New York.
 McKim, Mead & White, Architects.

necessary to continue this experiment at a greater length, as it is believed the idea is sufficiently developed in these four letters. In addition it is merely the theoretical part of the experiment that it is desirable to impress upon the draftsman. In practice it will be found advisable to make certain further variations from this "skeleton" in order to obtain the most pleasing effect possible with a single-line letter. But the basic relationship of these two forms will amply indicate the propriety of using them in combination or upon the same drawing.

It will be found that the letter more fully shown in Fig. 10 is almost the same as the letter produced by this "skeleton" method, except that it is more condensed. That is, the letters are narrower for their height and a little freer or easier in treatment. This means that they can be lettered more rapidly and occupy less space, and also that they will produce a more felicitous effect.

In actual practice, the free capitals shown in Fig. 10 will be found to be of the shape that can be made most rapidly and easily, and this style or some similar letter should be studied and practiced very carefully.

Other examples of similar one-line capitals will be found

used with classic outline or blacked-in capitals on drawings, Figs. 3, 5 and 7.

In Figs. 8, 9 and 13 these one-line letters are used for principal titles as well, and with good effect.

In Fig. 10 is shown a complete alphabet of this single-line

BILL OF INDIANA LIMESTONE
GENESEE VALLEY TRUST CO'S BUILDING

Fig. 8. Title from Architectural Drawing, Claude Fayette Bragdon, Architect.

letter, and the adaptability of this character for use on details is indicated by the title taken from one and reproduced in Fig. 9. In the same plate, Fig. 10, is also shown an excellent form of small letter that may be used with any of these capitals. It is

DETAIL N^o. (122) OF
FREESTONE SHEET C
405 COMMONWEALTH AVE
September. 8. 1901.
Frank. Chouteau. Brown. Architect.
N^o. 9. Park. Street. Boston Mass.

Fig. 9. Title from Detail.

quite as plain as any Engineer's letter, and is easier to make, and at the same time when correctly placed upon the drawing it is much more decorative. This entire plate is reproduced at a slight reduction from the size at which it was drawn, so that it may be studied and followed closely.

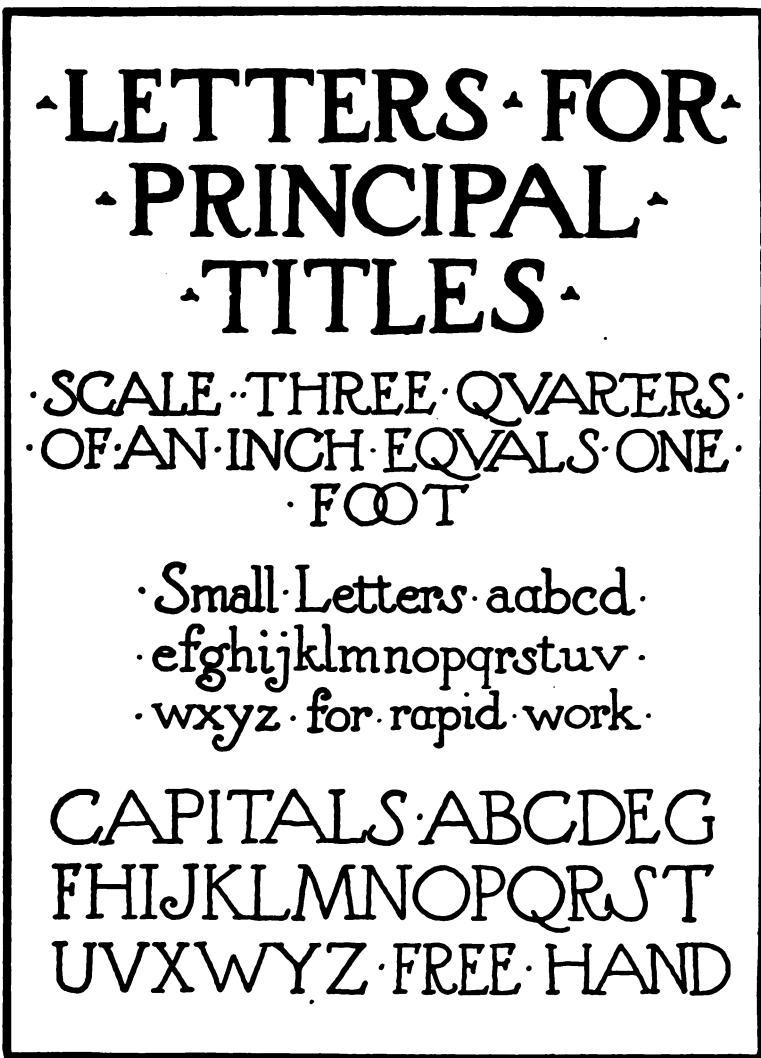


Fig. 10. Letters for Architectural Office use.

Fig. 10 should be most carefully studied and copied, as it represents such actual letter shapes as are used continually on



Fig. 11. Single-line Italic Letters, by Claude Fayette Bragdon.

architectural drawings, and such as would, therefore, be of the most use to the draftsman. He should so perfect himself in these alphabets that he will have them always at hand for instant use.

The alphabets of capital and minuscule one-line letters shown in Fig. 11 are similar in general type to those we have just been discussing, except that they are sloped or inclined letters and therefore come under the heading of "Italics." The Italic letter is ordinarily used to emphasize a word or phrase in a sentence where the major portion of the letters are upright;

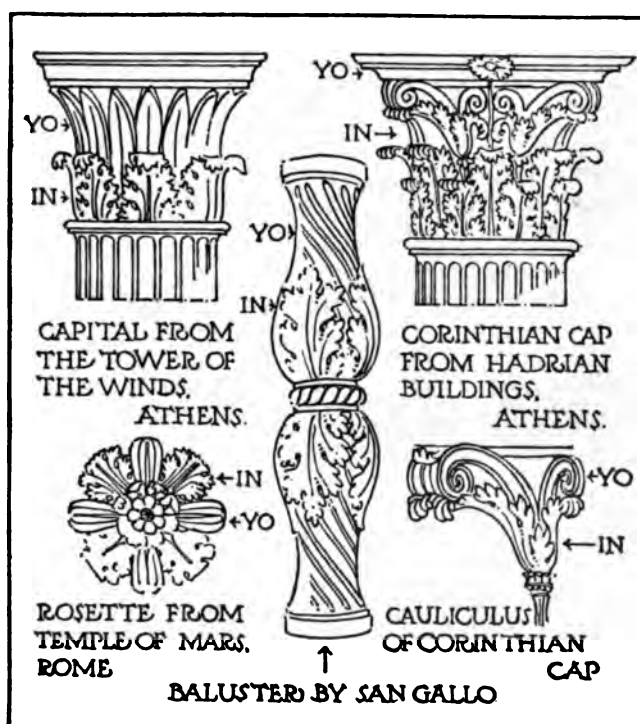


Fig. 12. Drawing, by Claude Fayette Bragdon.

but where the entire legend is lettered in Italics this effect of emphasis is not noticeable, and a pleasing and somewhat more unusual drawing is likely to result. If it is deemed advisable to emphasize any portion of the lettering on such a drawing, it is necessary only to revert to the upright form of letter for that portion.

The single-line capitals and small letters on the usual architectural plan or working drawing are illustrated in Fig. 13, where such a plan is reproduced. This drawing was not one made spe-

cially to show this point, but was selected from among several as best illustrating the use of the letter forms themselves, as well as good placing and composition of the titles, both in regard to the general outline of the plan and their spacing and location in the various rooms. It is apparent that it is not exactly accurate in the centering in one or two places. For instance, in the general title, the two lower lines are run too far to the right of the center line, and this should be corrected in any practice work where these principles will be utilized. It may be well to say that the actual length of this plan in the original drawing was thirteen inches, and the rest of it large in proportion. The student should not attempt to redraw any such example as this at the size of the illustration. He must always allow for the reduction from the original drawing, and endeavor to reconstruct the example at the original size, so that it would have the same effect when reduced as the model that he follows.

The letters for notes and more detailed information should be much simpler and smaller than and yet may be made to accord with the larger characters. Such a rapid letter as that shown in Fig. 10, for instance, may be used effectively with a severely classical title. Of course, no one with a due regard for propriety or for economy of time would think of using the Gothic small letter for this purpose.

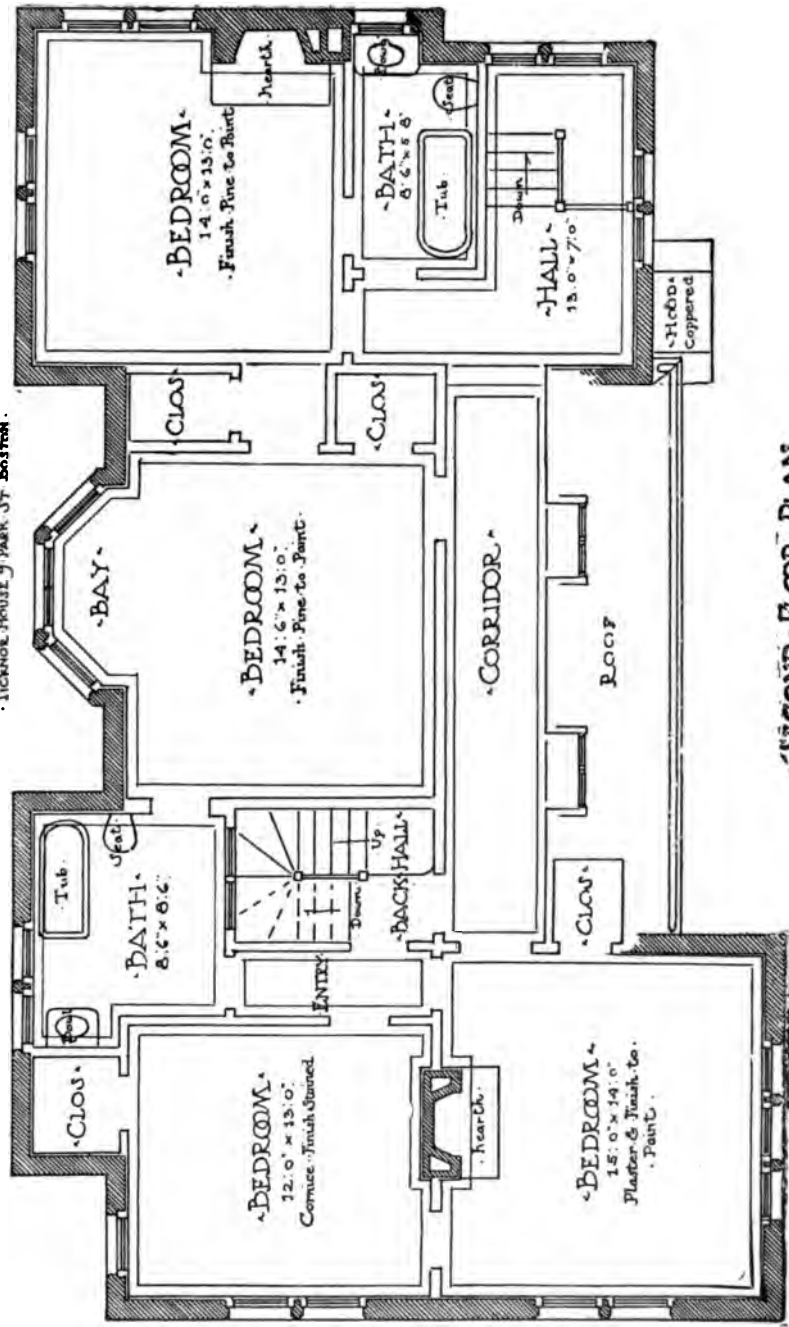
The portion of a drawing shown in Fig. 14 illustrates another instance of the use of lettering on an architectural working drawing. The lettering defined by double lines is in this case a portion of the architectural design, the two letters on the pendant banners being sewn on to the cloth while those on the lower portion of the drawing are square-raised from the background and gilded. Single-line capitals are used in this example for the notes and information necessary to understand the meaning of the drawing.

A drawing of distinction should have a principal title of equal beauty, such as that shown in Fig. 5 or Fig. 7. The excellent lettering reproduced in Fig. 12, from a drawing by Mr. Claude Fayette Bragdon, is a strongly characteristic and individual form, although based on the same "skeleton" idea as the other types of single-line lettering already referred to.

NEW HAMPSHIRE

June 1903

FRANK CHOUTEAU BROWN ARCHT.
TICKNOR HOUSE 9 PARK ST. BOSTON.



SECOND FLOOR PLAN

One Quarter Inch Scale

Fig. 12.

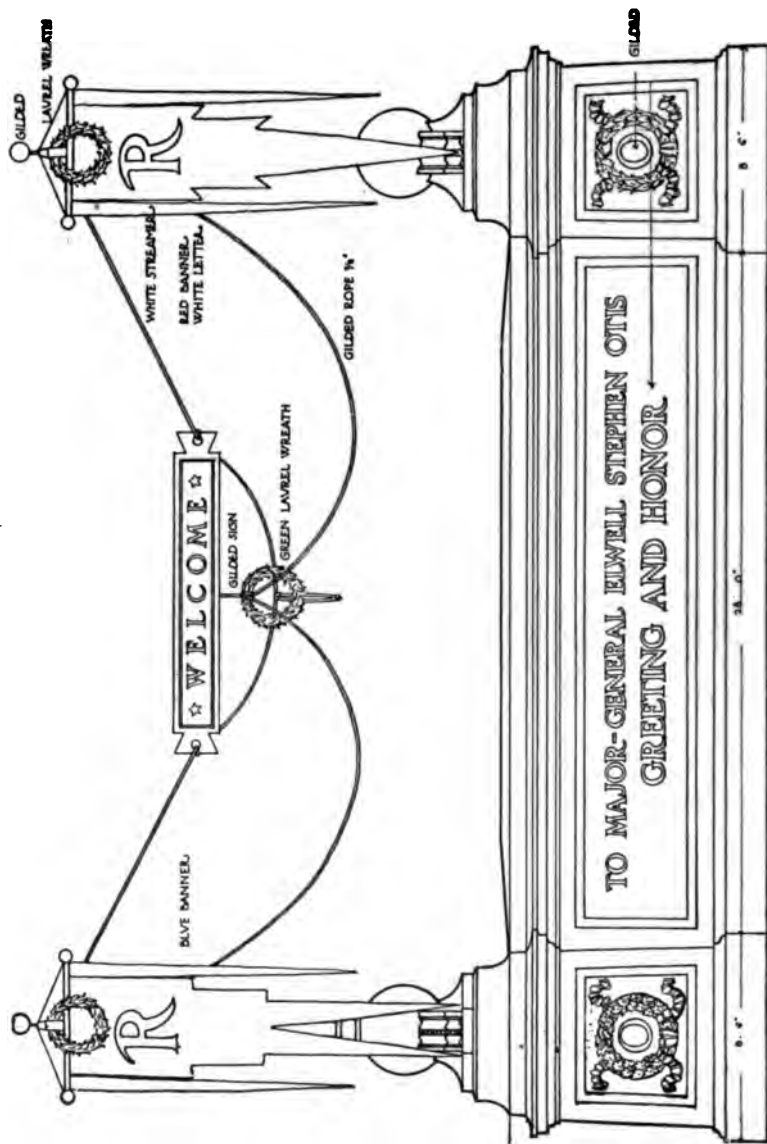


Fig. 14. Upper Portion of Drawing for Otis Memorial Arch, Claude Fayette Bragdon, Architect.

The "skeleton" letter, formed on the classic Roman letter, displays quite as clearly as does the constructive system of Albrecht Dürer, the distinctively *square* effect of the Roman capital. The entire Roman alphabet is built upon this square and its units. The letters shown in Figs. 22 and 23 are redrawn from rubbings of old marble inscriptions in the Roman Forum, and may be taken as representative of the best kind of classic letter



Fig. 15. Advertising Design, by Addison B. Le Boutillier.

for incision in stone. The Dürer letter, while a product of a later period, is fundamentally the same, and differs only in minor, if characteristic, details. However, for purposes of comparison it will serve to show the difference between a letter incised in marble, or in any other material, and one designed for use in lettering in black ink against a white background.

COMPOSITION.

After acquiring a sufficient knowledge of letter forms, the student is ready to begin the study of "lettering." While a knowledge of architectural beauty of form is the first essential, it

**BIGELOW, KENNARD AND CO
WILL HOLD, IN THEIR ART
ROOMS, MARCH 25 TO APRIL 6
INCLUSIVE, A SPECIAL EXHIBI-
TION AND SALE OF GRUEBY
POTTERY INCLUDING THE
COLLECTION SELECTED FOR
THE BUFFALO EXPOSITION
MDCCCCI**



**WASHINGTON STREET, COR-
NER OF WEST STREET, BOSTON**

Fig. 16. Cover Announcement, by Addison B. Le Boutillier.

is not the vital part in lettering, for the *composition* of these separate characters is by far the most important part of the problem.

Composition in lettering is almost too intangible to define by any rule. All the suggestions that may be given are of necessity laid out on merely mathematical formulæ, and as such are incapable of equaling the result that may be obtained by spacing and producing the effect solely from artistic experience and intuition. The final result should always be judged by its effect upon the eye, which must be trained until it is susceptible to the slightest deviation from the perfect whole. It is more difficult to define what good composition is in lettering than in painting or any other of the more generally accepted arts, and it resolves itself back to the same problem. The eye must be trained by constant study of good and pleasing forms and proportions, until it appreciates instinctively almost intangible mistakes in spacing and arrangement.

This point of "composition" is so important that a legend of most beautiful individual letter forms, badly placed, will not produce as pleasing an effect as an arrangement of more awkward letters when their composition is good. This quality has been so much disregarded in the consideration of lettering, that it is important the student's attention should be directed to it with additional force, in order that he may begin with the right feeling for his work.

An excellent example of composition and spacing is shown in Fig. 16, from a drawing by Mr. Addison B. Le Boutillier. The relation between the two panels of lettering and the vase form, and the placing of the whole on the paper with regard to its margins, etc., are exceptionally good, and the rendered shape of the vase is just the proper weight and color in reference to the weight and color of the lettered panels.

In this reproduction the border line represents the edge of the paper upon which the design itself was printed, and not a border line enclosing the panel. The real effect of the original composition can be obtained only by eliminating the paper outside of this margin and by studying the placing and mass of the design in relation to the remaining "spot" and proportions of the paper. Perhaps the simplest and most certain way to realize the

effect of the original is to cut out a rectangle the size of this panel from a differently colored piece of paper, and place it over the page as a "mask," so that only the outline of the original design will show through.

The other example by the same designer, shown in Fig. 15, is equally good. The use of the letter with the architectural ornament, and the form, proportion, spacing and composition of the lettering are all admirable.

The title page, by Mr. Claude Fayette Bragdon, shown in

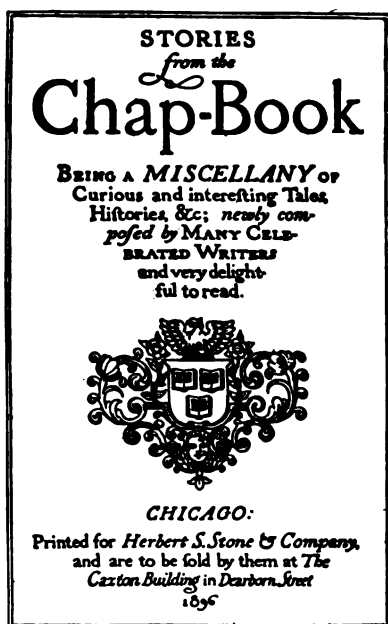


Fig. 17. Title Page, by Claude Fayette Bragdon.

Fig. 17, is a composition including the use of many different types of letters; yet all belong to the same period and style, so that an effect of simplicity is still retained. In composition, this page is not unlike its possible composition in type, but in that case no such variety of form for the letters would be feasible, while the entire design has an effect of coherence and fusion which the use of a pen letter alone makes possible, and which could not be obtained at all in typographical examples. The treatment of the ornament incorporated in this design should be noticed for its weight and rendering, which

bear an exact relation to the "color" of the letter employed.

In Fig. 18 is a lettered panel that will well repay careful study. The composition is admirable, the letter forms of great distinction—especially the small letters—and yet this example has not the innate refinement of the others. The decorative panel at the top is too heavy, and the ornament employed has no special beauty of form, fitness, or charm of rendering (compare Figs. 15 and 16), while the weight of the panel requires

some such over-heavy border treatment as has been used. Here, again, in the slight Gothic cusping at the angles a lack of restraint or judgment on the part of the designer is indicated, this Gothic touch being entirely out of keeping with the lettering itself, and only partially demanded by the decorative panel. Of course, it



Fig. 18. Advertising Announcement.

is easy to see that these faults are all to be attributed to an attempt to attract and hold the eye and thus add to the value of the design as an advertisement; but a surer taste could have obtained this result and yet not at the expense of the composition as a whole. It is nevertheless an admirable piece of work.

In Fig. 19 is shown an example of the use of lettering in

composition, in connection with a bolder design, in this case for a book cover, by Mr. H. Van Buren Magonigle. Note the nice sense of relation between the style of lettering employed and the design itself, as well as the subject of the work. The letter form is a most excellent modernization of the classic Roman letter shape (compare Figs. 22 and 23).



Fig. 19. Book Cover, by H. Van Buren Magonigle.

The student must be ever appreciative of all examples of the good and bad uses of lettering that he sees, until he can distinguish the niceties of their composition and appreciate to the utmost such examples as the first of these here shown. It is only by constant analysis of varied examples that he can be able to distinguish the points that make for good or bad lettering.

SPACING.

There is a workable general rule that may be given for obtaining an *even* color over a panel of black lettering; that is, if the individual letters are so spaced as to have an equal area of white between them this *evenness* of effect may be attained. But when put to its use, even this rule will be found to be surrounded by pitfalls for the unwary. This rule for spacing must not be understood to mean that it applies as well to *composition*. It does not: it is, at the best, but a makeshift to prevent one from going far wrong in the general tone of a panel of lettering, and must therefore fully apply only to a legend employing one single type of letter form.

One with sufficient authority and experience to give up dependence upon merely arbitrary rules, and to rely upon his own judgment and taste may, by varying sizes and styles of letters, length of word lines, etc., obtain a finer and much more subtle effect.

To acquire this authority in modern lettering it is necessary to observe and study the work turned out today by the best designers and draftsmen, such as the drawings of Edward Penfield, Maxfield Parrish, A. B. Le Boutillier and several others. The architectural journals, also, publish from month to month beautifully composed and lettered scale drawings by such draftsmen as Albert R. Ross, H. Van Buren Magonigle, Claude Fayette Bragdon, Will S. Aldrich and others, who have had precisely the same problem to solve as is presented to the draftsman in every new office drawing that he begins.

Of course, the freer and the further removed from a purely Classic capital form is the letter shape employed by the draftsman, the less obliged is he to follow Classic precedent; but at the same time he will find that his drawing at once tends more toward the bizarre and eccentric, and the chances are that it will lose in effectiveness, quietness, legibility and strength.

The student will soon find that he unconsciously varies and individualizes the letters that he constantly employs, until they become most natural and easy for him to form. This insures his developing a characteristic letter of his own, even when at the start he bases it upon the same models as have been used by many other draftsmen.

MINUSCULE OR SMALL LETTERS.

In taking up the use of the small or minuscule letter, a word of warning may be required. While typographical work may furnish very valuable models for composition and for the individual shapes of minuscule letters, they should never be studied for the *spacing* of letters, as such spacing in type is necessarily arbitrary, restricted and often unfortunate. Among the lower case types will be found our best models of individual minuscule letter forms, and the Caslon old style is especially to be commended in this respect; but in following these models the aim must be to get at and express the essential characteristics of each letter form, to reduce it to a "skeleton" after much the same fashion as has already been done with the capital letter, rather than to strive to copy the inherent faults and characteristics of a type-minuscule letter. The letter must become a "pen form" before it will be appropriate or logical for pen use; in other words, the necessary limitations of the instrument and material must be yielded to before the letter will be amenable to use for lettering architectural drawings.

The small letters shown in Figs. 17, 18 and 20 are all adapted from the Caslon or some similar type form, and all exhibit their superiority of spacing over the possible use of any type letter. Fig. 20 is a particularly free and beautiful example indicating the latent possibilities of the minuscule form that are as yet almost universally disregarded. An instance of the use of the small letter shown in a complete alphabet in Fig. 10, may be seen in Figs. 9 and 13.

In lettering plans for working drawings, the small letter is used a great deal. All the minor notes, instructions for the builders or contractors, and memoranda of a generally unimportant character, are inscribed upon the drawing in these letters. Referring again to Fig. 10, the letters at the top of the page would be those used for the principal title, the name of the drawing, the name of the building or its owner, while the outline capitals would be used in the small size beneath the general title, to indicate the scale and the architect, together with his address. In a small building, or one for domestic use, these same letters would be employed in naming the various rooms, etc., although in an

elaborate ornamental or public building, letters similar to those in the principal title might be better used, while the minuscule letter would be utilized for all minor notes, memoranda, directions, etc. By referring to Figs. 3, 5, 7, 8, 9, 13 and 14, examples from actual working drawings and plans are shown, which should sufficiently indicate the application of this principle.

It must again be emphasized that practice in the use of these forms combined together in words, as well as in more difficultly composed titles and inscriptions where various sizes and kinds of letters are employed, is the only method by which the draftsman can become proficient in the art of lettering; and even then he must intelligently study and criticise their effect

INTERLVDES
beneath the lines of SIR
RICHARD LOVELACE'S
POEM called — "To Lucafta
on going to the vvars"
vvhich saith :

Fig. 20. Pen-drawn Heading, by Harry Everett Townsend.

after they are finished, as well as study continually the many good drawings carrying lettering reproduced in the architectural journals. For this purpose, in order to keep abreast of the modern advance in this requirement, he must early learn to distinguish between the instances of good and bad composition and lettering.

ARCHITECTURAL INSCRIPTION LETTERING.

The use of a regular Classic letter for any purpose necessitates the reversion to and the study of actual Classic examples for spacing and composition. In using this letter in a pen-drawn design, certain changes must be made in adapting it from the incised stone-cut form—which variations are, of course, practically the reverse of those required in first adapting the letter for use in stone. The same letter for stone incision requires, in addition, a careful consideration of the nature of the material, and the spacing and letter section that it allows. Also the effect

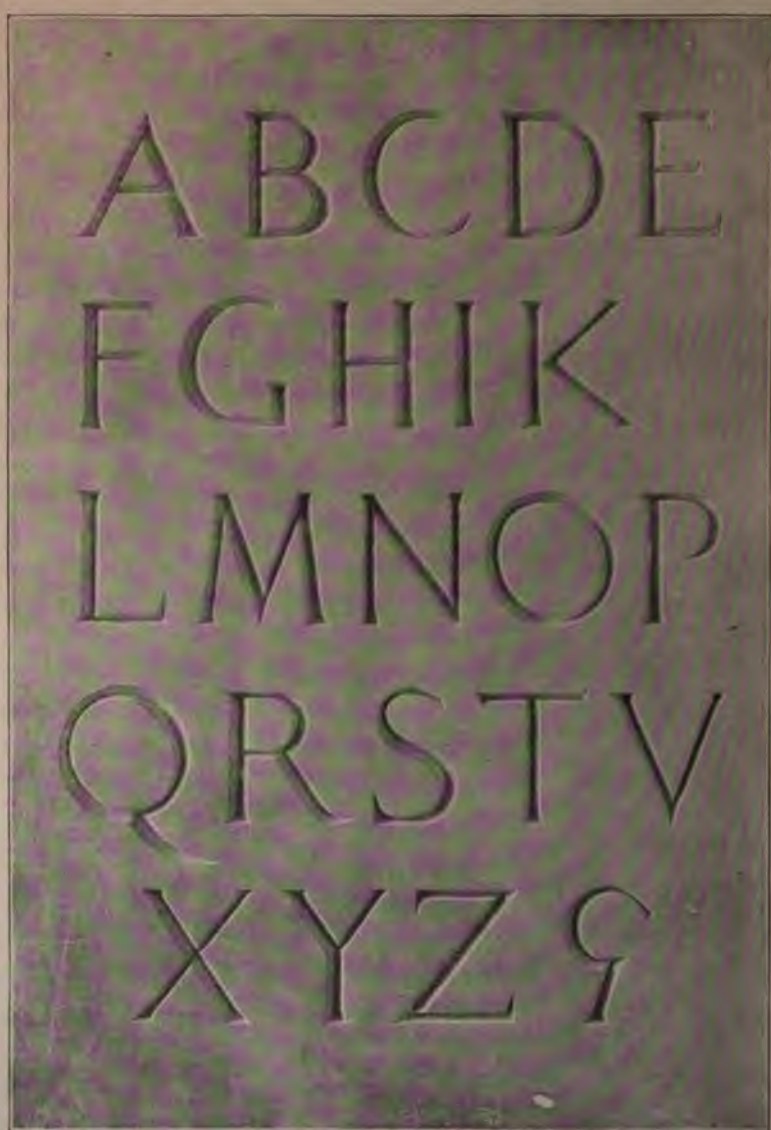


Fig. 21. Study for Lettering on Granite Frieze of Boston Public Library, McKim, Mead & White, Architects.

of a letter in the inscription in place must be carefully studied, its height above or below and relation to the eye of the observer. The fact is that the letter form must in this case be determined solely by the light and shadow cast by the sun on a clear, bright day, or diffused more evenly on a cloudy one. If in an interior location its position in regard to light and view-point is even more important, as the conditions are less variable.

CLASSIC ROMAN LETTERS.

In any letter cut in stone, or cast in metal, it is not the outline of the letter that is seen by the eye of the observer, but the *shadow* cast by the *section used to define the letter*. This at once changes the entire problem and makes it much more complicated. In incising or cutting a letter into an easily carved material, such as stone or marble, we have the examples left us by the inventors, or at least the adapters, of the Roman alphabet. They have generally used it with a V-sunk section, and in architectural and monumental work this is still the safest method and the one most generally followed. One improvement has been made in adapting it to our modern conditions. The old examples were most often carved in a very fine marble which allowed a deep sinkage at a very sharp angle, thus obtaining a well-defined edge and a deep shadow. In most modern work the letters are cut in sandstone or even in such coarse material as granite, where sharp angles and deep sinkage of the letter-section is either impossible, or for commercial reasons influencing both contractors and stonecutters, very hard to obtain. To counterbalance this fault a direct sinkage at right angles to the surface of the stone before beginning the V section has been tried, and is found to answer the purpose very well, as it at once defines the edge of the letter with a sharp shadow. See the two large sections shown in the upper part of Fig. 31.

This section requires a letter of pretty good size and width of section, and, therefore, may be used only on work far removed from the eye, as is indeed alone advisable. An inscription that is to be seen close at hand must rely upon the more correct section and be cut as deeply as possible. For lettering placed at a great height, an even stronger effect may be obtained by making the incised section square, and sinking it directly into the stone.

Such pleasant grading of shadows as may be attained by the other method is then impossible, and there are no subtle cross

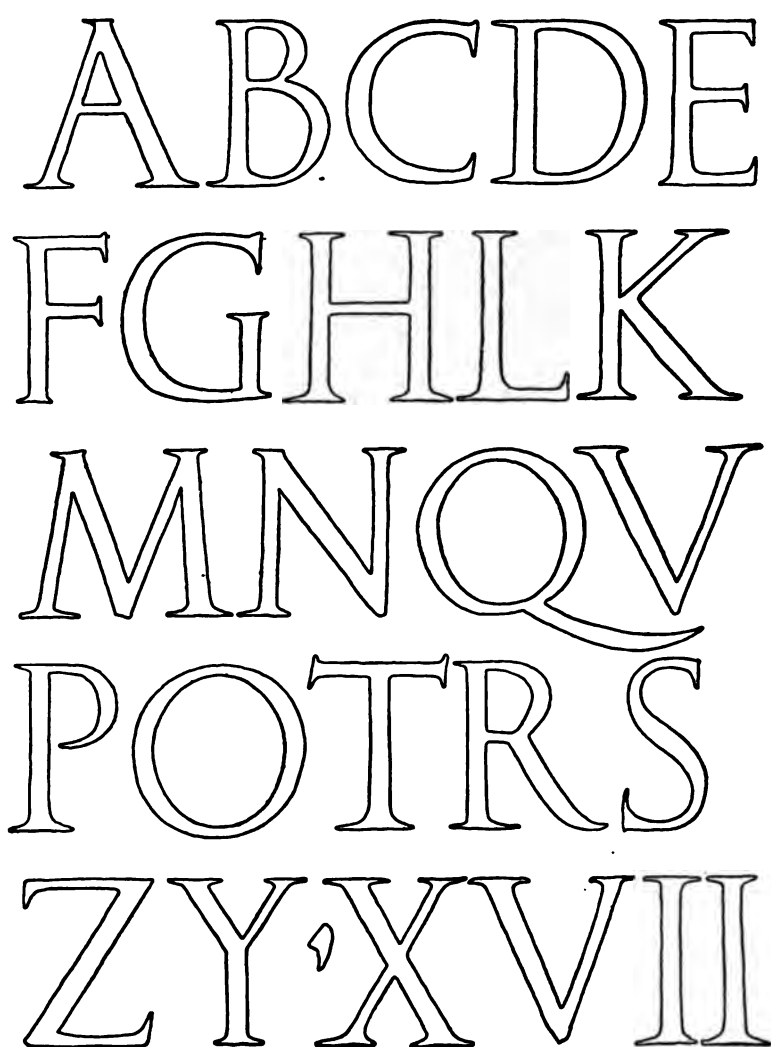


Fig. 22. Classic Roman Alphabet.
From Marble Inscriptions in the Roman Forum.

lights on the rounding letters to add interest and variety, but the letter certainly carries farther and has more strength.

In Fig. 21 is shown a photograph from a model of the incised V-sunk letters cut in granite on the frieze of the Boston

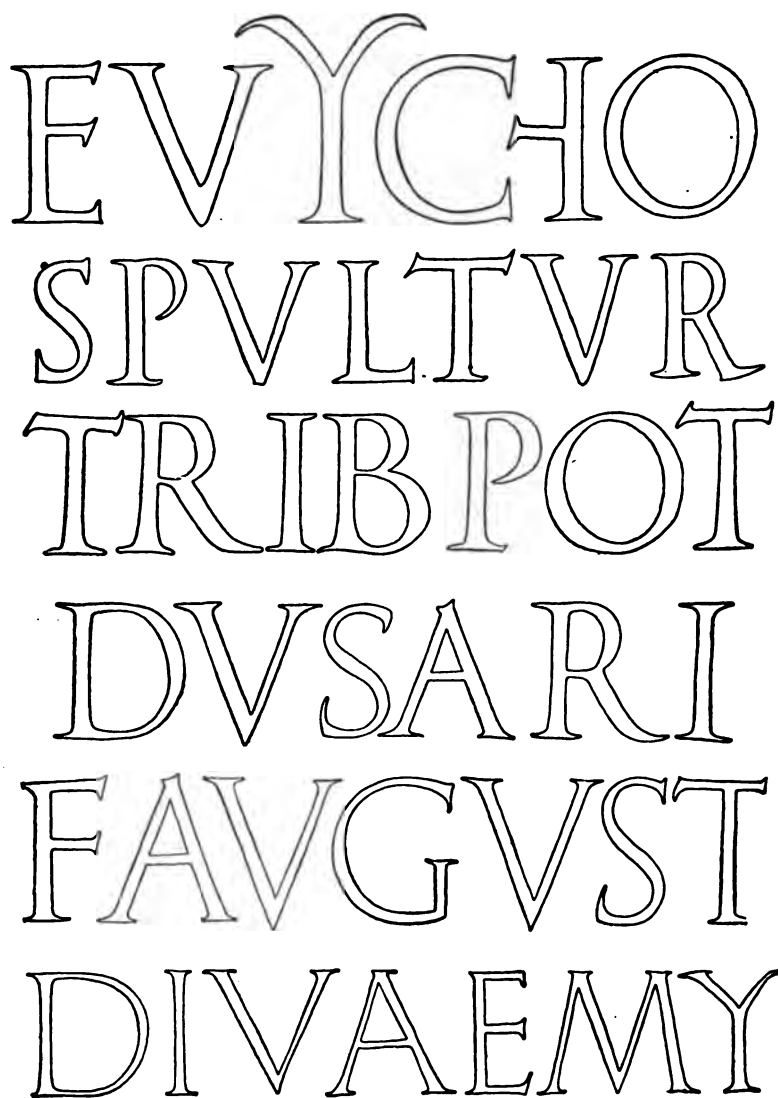


Fig. 23. Fragments of Classic Roman Inscriptions.

Public Library. This photograph indicates the shadow effect that defines the incised form of the letter, and will assist the student

somewhat in determining the section required for the best effect. It will be observed that this letter is different in character from the one used by the same architects in a different material, sandstone, shown in Fig. 24.

In Fig. 22 is shown an alphabet redrawn from a rubbing of Roman lettering, and in Fig. 23 are shown portions of Classic inscriptions where letters of various characters are indicated. These letters were very sharply incised with a V-sunk section in marble, and were possibly cut by Greek workmen in Rome. It is on some such alphabet as this that we must form any modern letter to be used in a Classic inscription or upon a Classic building. These forms should be compared with the letters shown in Fig. 24, on the Architectural Building at Harvard, by McKim, Mead & White, architects, where they were employed with a full understanding of the differences in use and material. The Roman letter was cut in marble; the modern letter in sandstone. Both were incised in the V-sunk section, but the differences in material will at once indicate that the modern letter could not have been cut as clearly nor as deeply as the old one. The modern letter was done a little more than twice the original size of the old one, which explains certain subtleties in its outline as here drawn. The sandstone being a darker material than the marble, the letter should of necessity be heavier and larger in the same location, in order to "carry" or be distinguishable at the same distance; while the Classic example, being sharply and deeply cut in a beautiful white material which even when wet retains much of its purity of color, would be defined by a sharper and blacker outline, and therefore be more easily legible, other conditions being the same, even for a longer distance. In both these figures, the composition of the letters may be seen to advantage, as in even the Classic example, where they are alphabetically arranged, they are placed in the same relation to each other as they held in the original inscription. A complete alphabet of the letter shown in word use in Fig. 24, is shown at larger size in Fig. 25.

Although the lettering of the Italian Renaissance period was modeled closely after the Classic Roman form, it was influenced by many different considerations, styles and peoples.

VITRUVIUS
APOLLODORUS
CALLICRATES
POLYCLITUS
DINOCRATES

Fig. 24. Lettering from Harvard Architectural Building. McKim, Mead & White, Architects.

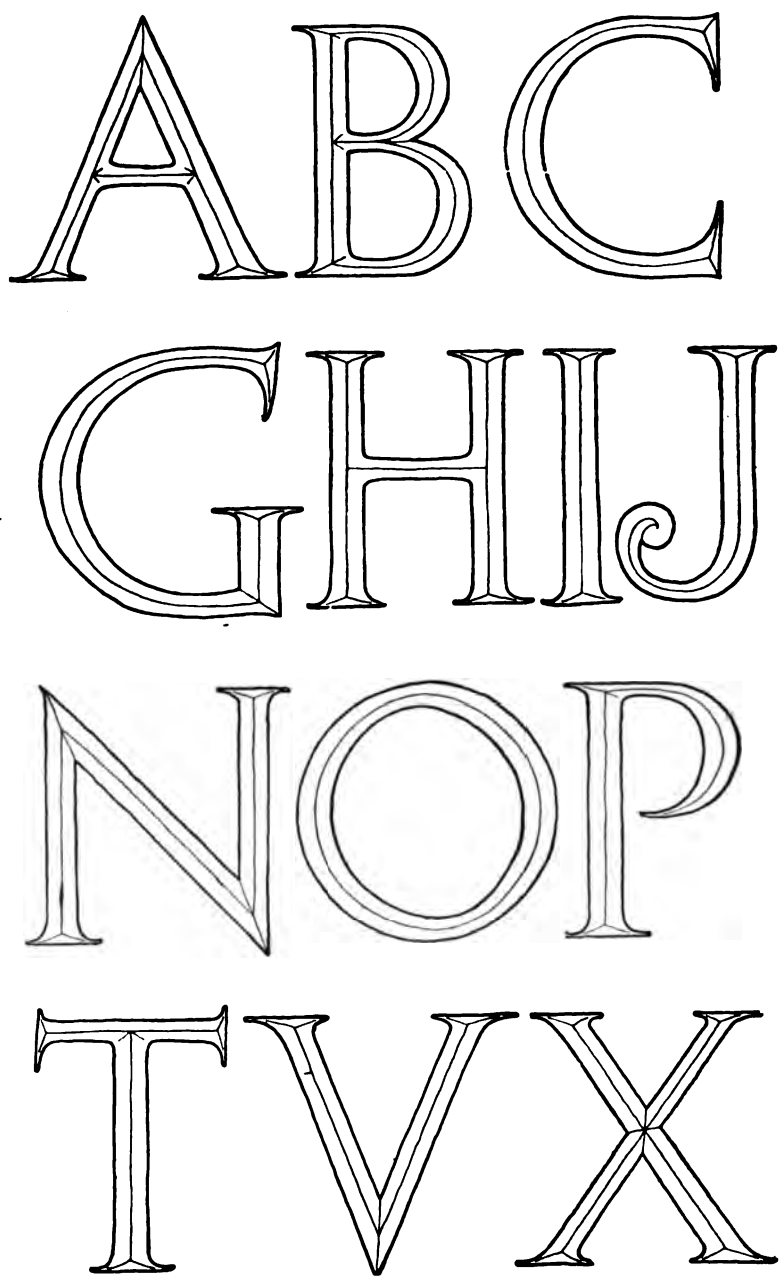


Fig. 25. Complete Alphabet.
Redrawn from Inscription on Architectural Building (See Fig. 24).

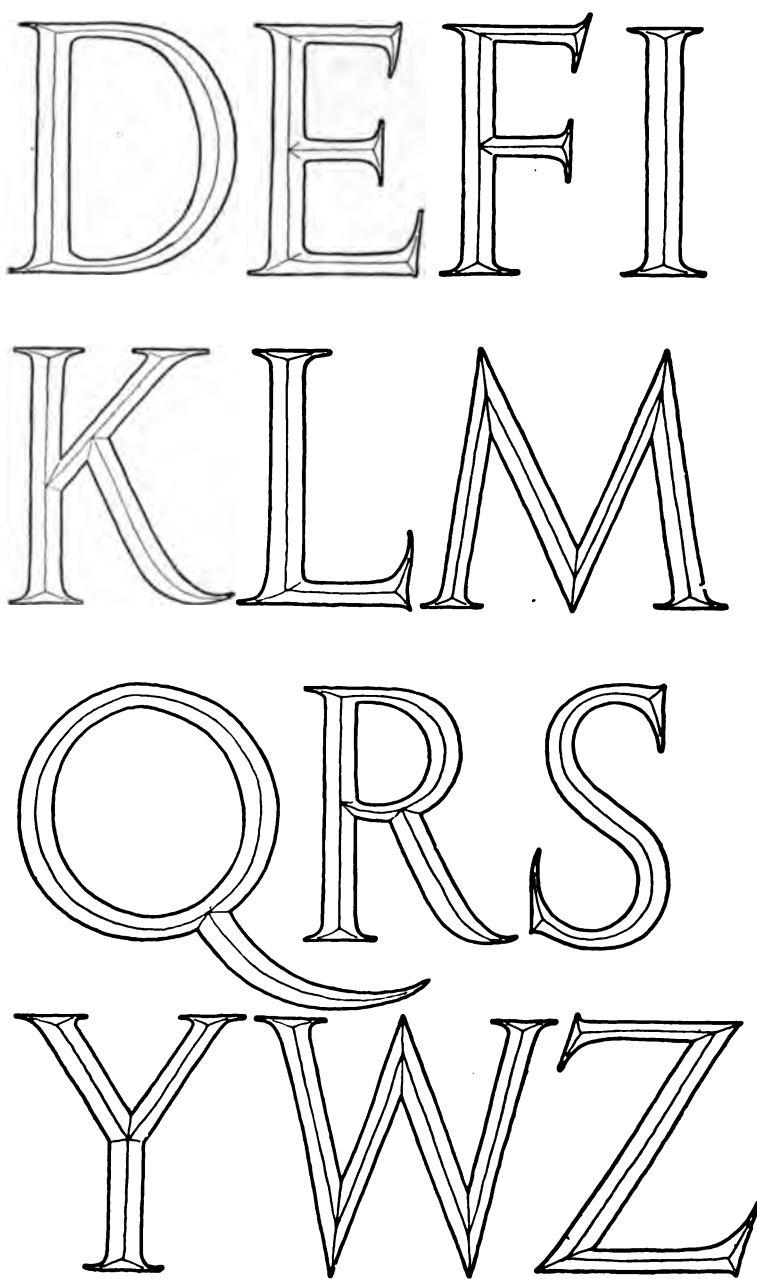


Fig. 25. (Continued)

MARMORA
I INGENIO C
QVAE NATV
KAROLVS I
AVSONIAE 7
OCCIDIT
OM NOVIT.

Fig. 26. Fragment of Italian Renaissance Inscription.
From the Marsuppini Tomb in Florence.

ITALIAN RE-
NAISSANCE
LETTERING
ABCDEFGFG
HIJKLMNE
OPQRSTU
VXWYZ

Fig. 27. Italian Renaissance Lettering.
Adapted from Inscription shown in Fig. 26.

In Fig. 26 is shown a fragment of the inscription on the Marsuppini tomb at Florence. This outline letter was traced from a rubbing, and shows very nearly the exact character of the original, a marble incised letter. Fig. 27 is an alphabet devised



Fig. 28. Italian Renaissance Inscription at Bologna.

from this incised letter for use as a pen-drawn form and redrawn at the same size. It will be noticed that in the letters shown in the four lower lines a quite different serif* treatment has been adopted, and certain of the letters, such as the E's, have been



Fig. 29. Italian Renaissance Inscription, Chiaravalle Abbey in Milan.

“extended” or made wider in proportion. These variations are such as modern taste would generally advocate, but in the first three lines of this plate the feeling, serif treatment and letter width of the original have been retained; the only change has

*NOTE. The “serif” is the short spur or cross stroke used to define and end the main upright and horizontal lines of the letter.



Fig. 30. Alphabet of Uncial Gothic Capital Letters, 16th Century.

been to narrow up the thin lines in relation to the thick lines to the proportions that they should have in a solidly black and inked-in letter form.

The two small panels, one from a monument in Bologna, and one from the Chiaravalle Abbey in Milan, Figs. 28 and 29, show a letter which was incised in stone and follows the so-called uncial or round form, with characteristics showing the probable influence of the Byzantine art and period. These two inscriptions may be compared with another alphabet showing the uncial character when used in black against a white page, as in Fig. 30. This same style of letter was often used in metal, and may be seen in many of the mortuary slabs of this and succeeding periods.

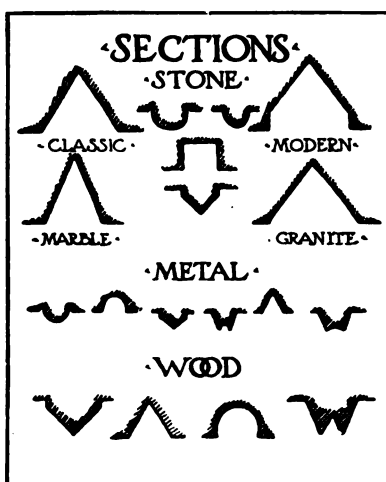


Fig. 31. Inscription Letter Sections.

In many of the Renaissance wall monuments the V-sunk letter sections have been filled with a black putty to make the letter very clear, and when this falls out, as it often does, the V-cut section may still be seen behind it. Also in many Italian floor slabs the letters are either V-sunk or shallow, square sinkages filled with mastic, or sometimes they are of inlaid marble of a color different from the ground. Again a V-sunk letter section sometimes carries an additional effect because it is smoothly cut



Fig. 32. English 17th Century Letters, from Tombstones.

and finished and the surface of the stone is left rough, thus obtaining a different texture and color effect; or, though more rarely, the opposite treatment may be used. Then, again, the sides of the letter sinkage may be painted or gilded. Often even the shadow is painted into the section, but this is generally done on interior cutting where there is no direct light from the sun, because if direct sunlight does fall upon a letter so treated, a very amusing effect occurs when the shadow is in any other position than that occupied by the painted representation.

For still further effects, *raised lettering* may be cut on stone surfaces. This is more expensive, as it necessitates the more labor in cutting back the entire ground of the panel, but for certain purposes it is very appropriate.

In such a letter the section may be a raised V-shape, or it may be rounded over to make a half circle in section, as drawn in Fig. 31. This latter form is especially effective in marble, but it is, of course, very delicate and does not carry to any great distance. Its use should be restricted to small monumental headstones or to lettering to be read close to, and below the level of, the eye.

A raised letter is more generally appropriate for cast copper and bronze tablets, when its section may be a half round, a raised V-form, or square-raised with sharp corners; or, better still, a combination of square and V-raised with a hollow face. See Fig. 31. Experience has proved that this last-named section produces the most telling letter for an ordinary cast-metal panel.

Fig. 32 shows an alphabet of a letter derived from English tombstones. This letter was cut in slate or an equally friable material, and was comparatively shallow. A certain tendency toward easing the acute angles may be observed in this alphabet, evidently on account of the nature of the material in which it was carved rendering it easily chipped or broken.

In wood carving, a letter exactly reversing the V-sunk section with direct sinkage, gives the best effect for a raised letter.

Every material, from its nature and limitations, requires special consideration. A letter with many angles is not adapted to slate, as that material is liable to chip and sliver; hence an



Fig. 33. German Black Letters, from a Brass.

uncial form with rounded angles suggests itself (as in Fig. 29), and is, indeed, frequently used.

It would be quite impossible to take up in detail the entire list of available materials and consider their limitations at length, as the task would be endless. For the same reason, it is not possible to take up each letter style and consider its use in stone and other materials. Of course, a Roman letter or any other similar form when drawn for stone-incised use must have its narrow lines at least twice as wide as when drawn in ink, black against a white background. (Compare Figs. 26 and 27.)

Experience and intuition combined with common sense will go farther than all the theory in the world to teach the limitations



Fig. 34. Black-Letter Alphabet.

required by letter form and material. The student, however, should bear in mind that it is not necessary that he himself should make a number of mistakes in order to learn what *not* to do. He may get just as valuable information at a less cost by observing the mistakes and successes of others in actually executed work, and avail himself of their experience by applying it with intelligence to his own problems and requirements.

GOTHIC LETTERING.

Gothic lettering is extremely difficult, and has little practical use for the architectural designer or draftsman. It is often appropriate, but it is quite possible to get along without employing this form at all. However, in case he should require a letter of this style, it would be better to refer him to some book where he may study its characteristics more particularly, remembering it is just as important he should know something of the history,

ARCHITECTURAL LETTERING

uses and materials from which this letter has been taken, and any instance of the use of the Roman form. Indeed, it might

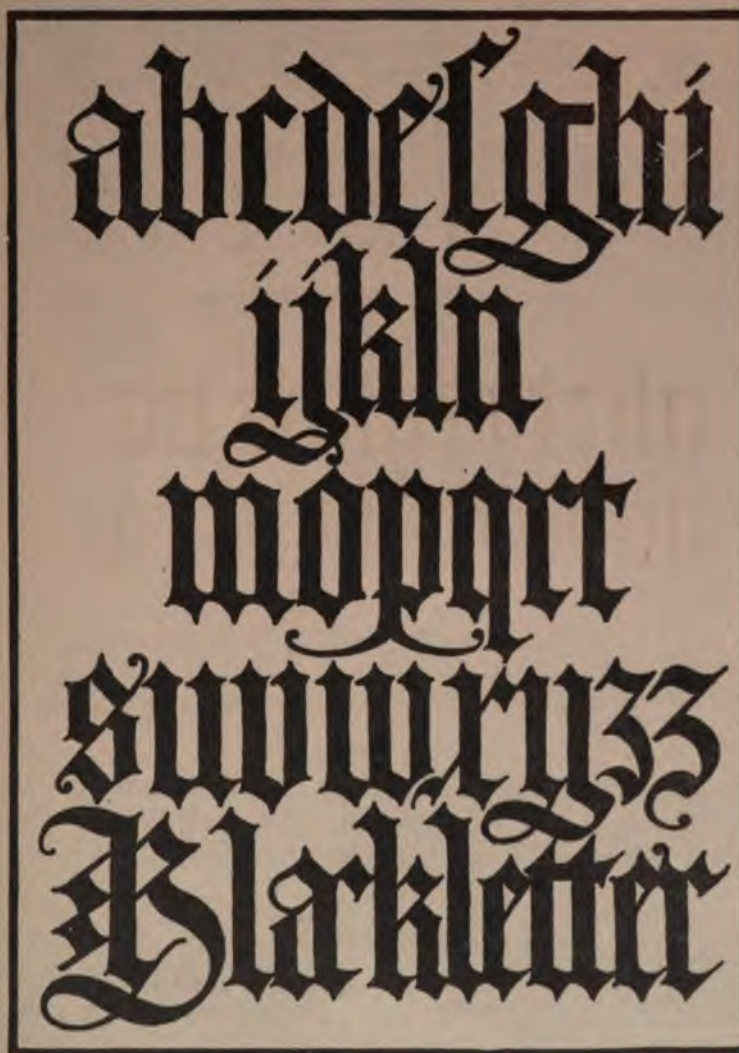


Fig. 35. Italian Black Letters, after Bergomensis.

said, it is even more important, as the Gothic letter is more universally misunderstood and misapplied than the simpler Roman letter.

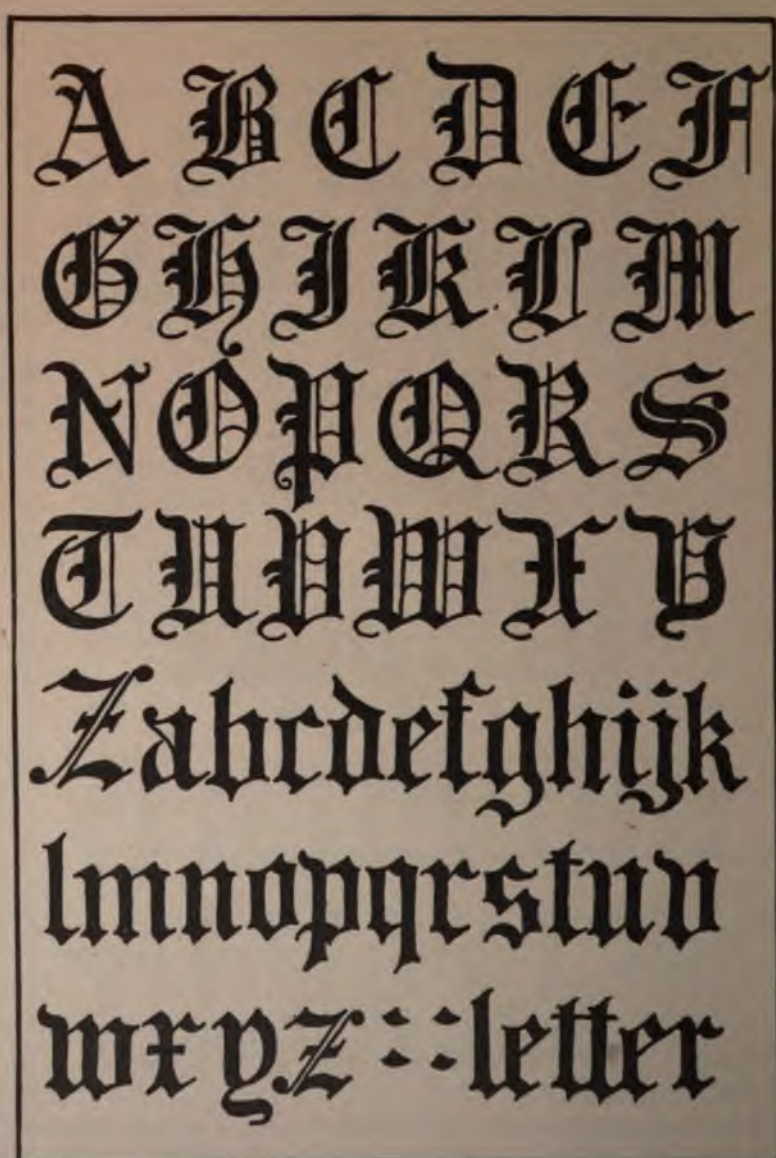


Fig. 36. English Gothic Text.

The alphabet of German black letters shown in Fig. 35 is taken from a very beautiful example of Gothic black letter devised by Jacopus Phillipus Foresti (Bergomensis) and used by him in the title page of "*De Claris Mulieribus*," etc., published in Ferrara in 1497. Although Italian, this letter is as German in character as any of the examples from the pen of Albrecht Dürer. A German black letter redrawn from a brass is shown in Fig. 33, while an English form of Gothic letter is shown in Fig. 36.

In Fig. 34 is another example of a black-letter alphabet. The entire effect of a black-letter page depends upon the literal interpretation of the title "black letter." That is, the space of white between and among the letters should be overbalanced by the amount of black used in defining the letter form itself.

Inasmuch as this letter is likely to be used but little by architectural draftsmen, and as it is a much more difficult form to compose than even the Roman type, it seems better to refer the student to some treatise where its characteristics are taken up more thoroughly and at greater length.

Any draftsman having occasion to use lettering to any extent should have some fairly elaborate textbook always at hand for reference.

EXAMINATION PLATES.

In addition to the following Examination Plates the student is expected to make careful reproductions of the lettering in this Instruction Paper. These plates need not be sent to the School.

PLATES I, II, III.

Draw the alphabet, using the same construction as given in Figs. 1 and 2, and making each letter two inches high. Put ten letters on each of the first two plates, and on the third arrange the remainder, including the two forms of W given in Fig. 2.

PLATE IV.

Make a careful reproduction of Fig. 10 on the left-hand side of the plate. The letters should be of the same size as in Fig. 10. On the right-hand side of the plate use the letter forms shown in Fig. 10 and of the same size, and letter the following title, arranging the legend to look well on the plate: Front Elevation, Country House at Glen Ridge, New Jersey, Aug. 24, 1903. David Carlson Mead, Architect, No. 5925 State St., Chicago, Ill.

PLATE V.

Reproduce on this plate Figs. 27 and 32 of the Instruction Paper, using letters of the same size.

PLATE VI.

On the left-hand side of this plate, copy the lettering shown in Fig. 9, making the letters at least as large as those in the illustration. On the right-hand side, following the same style and size, letter the following title: Detail of Entrance Porch, Country House at Glen Ridge, New Jersey, Sept. 10, 1903. David Carlson Mead, Architect, No. 5925 State St., Chicago, Ill.

This plate to be done in pencil only.

PLATE VII.

Using individual letter forms like those shown in Figs. 24 and 25, letter the following title: Museum of Architecture, Erected in Memory of John Howard Shepard, First President Technology, Bangor, Me.

The letters should be of a size suited to the title; the title should occupy five lines.

All plates except Plate VI should be inked in. The student should first lay out his lettering in pencil in order to obtain the proper spacing of the center line on his page or panel. He should also place guide lines in pencil at the top and bottom of his lettering for both capitals and small letters.

The plates should be drawn on a smooth drawing paper 11 inches by 15 inches in size. The panel inside the border lines should be 10 inches by 14 inches. For best work Strathmore (smooth finish) or Whatman's hot-pressed drawing paper is recommended.

The date, the student's name and address, and the plate number should be lettered on each plate in one-line letters such as are shown in Fig. 10.



**This book is under no circumstances to be
taken from the Building**

[illegible]



